MONTHLY WEATHER REVIEW

CLEVELAND ABBE, Editor.

VOL. 42, No. 5
W. B. No. 533

MAY, 1914.

CLOSED JUNE 30, 1914
ISSUED AUG. 25, 1914

INTRODUCTION.

During the summer of 1913 the Secretary of Agriculture established a board to reorganize the system of publications of the Department of Agriculture. In accordance with the proceedings of the board and the suggestions from representatives of the Weather Bureau, the "Bulletin of the Mount Weather Observatory" ceased to be published with the completion of its volume 6. Any subsequent contributions from the members of the research staff that would have been proper for that Bulletin will be incorporated in the Monthly Weather Review. The climatological service of the Weather Bureau will be maintained in all its essential features, but its publications, so far as they relate to purely local conditions, will be incorporated in the monthly reports for the respective States, Territories, and colonies.

Beginning with January, 1914, the material for the Monthly Weather Review will be prepared and classified in accordance with the following sections:

SECTION 1.—*Aerology.*—Data and discussions relative to the free atmosphere.

SECTION 2.—*General meteorology.*—Special contributions by any competent student bearing on any branch of meteorology and climatology, theoretical or otherwise.

SECTION 3.—*Forecasts and general conditions of the atmosphere.*

SECTION 4.—*Rivers and floods.*

SECTION 5.—*Bibliography.*—Recent additions to the Weather Bureau library; recent papers bearing on meteorology.

SECTION 6.—*Weather of the month.*—Summary of local weather conditions; climatological data from regular Weather Bureau stations; tables of accumulated and excessive precipitation; data furnished by the Canadian Meteorological Service; monthly charts Nos. 1, 2, 3, 4, 5, 6, 7, 8, the same as hitherto.

In general, appropriate officials will prepare the six sections above enumerated; but all students of atmospherics are cordially invited to contribute such additional articles as seem to be of value.

The voluminous tables of data and text relative to local climatological conditions that have during recent years been prepared by the 12 respective "district editors" will be omitted from the Monthly Weather Review, but will in future be collected and published by States at selected section centers.

The data needed in section 6 can only be collected and prepared several weeks after the close of the month whose name appears on the title page; hence the Review as a whole can only issue from the press within about eight weeks from the end of that month.

The Annual Summary of the Review will hereafter appear as an Annual Supplement containing the essential tables heretofore published in the annual Report of the Chief of the Weather Bureau.

It is hoped that the meteorological data hitherto contributed by numerous independent services will continue as in the past. Our thanks are especially due to the following directors and superintendents:

The Meteorological Service of the Dominion of Canada.
The Central Meteorological and Magnetic Observatory of Mexico.
The Director General of Mexican Telegraphs.
The Meteorological Service of Cuba.
The Meteorological Observatory of Belen College, Habana.
The Government Meteorological Office of Jamaica.
The Meteorological Service of the Azores.
The Meteorological Office, London.
The Danish Meteorological Institute.
The Physical Central Observatory, St. Petersburg.
The Philippine Weather Bureau.
The General Superintendent United States Life-Saving Service.

52003—14——1

SECTION I.—AEROLOGY.

THE INFLUENCE OF METEOROLOGICAL CONDITIONS ON THE PROPAGATION OF SOUND.

By HARRY BATEMAN, Ph. D. Johnston Scholar.

(Dated Johns Hopkins University, Baltimore, Md., June 5, 1914.)

§1. THE INFLUENCE OF THE WIND.

The effect of wind on the velocity of propagation of sound was first established by a long series of experiments by Dr. Derham (1). He observed that the time taken by the report of a cannon in traveling a distance of 12½ miles across the Thames from the grounds of Blackheath varied between 55½ and 61 seconds according as the wind and sound traveled in the same or in opposite directions. A negative result had previously been obtained by some members of the Accademia del Cimento at Florence, but the observations were made at distances of not more than two or three miles from the source of sound and the difference in the time due to the effect of the wind is so small that, as Derham remarked, it is not surprising that it escaped observation.

Derham paid more attention to the effect of wind on the velocity of sound than to its effect on the range and audibility of sound. A passage which Derham quotes from an account of the work of Joseph Averiani (2) shows that the existence of the latter effect was recognized, but its cause was not then understood.

> Nor is there need of favoring winds to promote this passage of sound in order that it may be surely heard. Indeed, any wind whatsoever, whether it be favorable or adverse, is equally an impediment, and renders the sound less audible. It may be because the roar of the sea, agitated by this cause, is more a disadvantage than the current of air blowing in the same direction is an advantage. Hence it is that the sound is heard only when the wind is entirely still or is only murmuring very gently, when the air is serene and the sea tranquil. Nor then, indeed, is it heard indiscriminately from all points, but from those only which are a little the more elevated * * *.

These remarks are interesting because two phenomena are recorded which have been observed in more recent experiments. The effect of wind in reducing the audibility of sound was noticed, for instance, by de la Roche (3) who compared the sounds from two equal bells placed at such distances from the observer in different directions that the sounds from them appeared to be equally distinct. De la Roche found that the distance for a direction at right angles to the wind was greater than for directions with or against the wind. This result led some men to the erroneous conclusion that sound had a greater *range* in a direction at right angles to the wind than in other directions. This error was corrected by the experiments of Joseph Henry (4) and Osborne Reynolds (5), which showed very clearly that the range with the wind is generally about double that at right angles to the wind. Reynolds says:

> It does not follow, however, nor was the fact observed that at comparatively short distances the sound with the wind was more *intense* than at right angles.

De la Roche, Henry, and Reynolds also noticed that a sound which was practically inaudible close to the ground or surface of the sea could often be heard at a greater altitude, for instance on the top of a tree or cliff or at the masthead of a ship. Thus Averiani's observation has been abundantly confirmed. The well-known fact that the sound of a bell can be heard over a wider area when the bell is raised above the ground belongs to the same order of ideas. This fact has been applied with advantage in the case of school bells and church bells.

These phenomena seemed very mysterious until it was shown by Stokes and Reynolds that they were due to refraction of sound waves by the atmosphere. At the Dublin meeting of the British Association in 1857 Stokes pointed out that when the velocity of the wind increases overhead rays of sound traveling to windward are gradually bent upward and at a moderate distance pass over the head of the observer while rays traveling with the wind are bent downward. An observer to leeward of the source hears by a direct ray which starts with a slight upward inclination and has the advantage of being out of the way of obstruction for the greater part of its course (6). Stokes explained De la Roche's observation that at short distances sound is most intense in a direction at right angles to the ground by saying that in this direction a ray which reaches the observer after being reflected from the ground has very nearly the same direction as the direct ray, consequently the two rays produce a greater intensity of sound in this direction than in any other.

This idea of a refraction of sound due to a vertical gradient of wind velocity was adopted and developed by Joseph Henry in his discussion of the results of the experiments with fog signals made by a committee appointed by the United States Lighthouse Board. (7)

The same idea was evolved by Reynolds before he became acquainted with the work of Stokes, and was used to explain the results of his experiments. It was also taken up by Alexander Beazeley (8), who suggested that the range of sounds to be sent against the wind could be increased by raising the source and projecting the sounds slightly downward.

The fact that the propagation of sound can not be described so accurately as in the case of light, by using the idea of a ray has been regarded as a difficulty in Stokes's theory. Reynolds discusses the question by considering the analogous case of diffraction of light and concludes that at short distances the effect produced by a lateral diffusion of the sound would be small. Major Dutton (9) considered that the lateral diffusion might to some extent counteract the effect of refraction and Henry used the same idea to explain how sound which had been refracted upward could reach the earth again (10). Henry also showed that a return of the sound to the earth could be accounted for in another way, by postulating the existence of an upper current of air blowing in the opposite direction to the lower one. The latter bends the rays of sound upward when they are directed against it, whereas the former current causes a downward bend which brings the rays to earth again. With the aid of this idea Henry accounted for the regions of silence and abnormal audibility observed by Gen. Duane in 1871 during a northeast snowstorm (11). The idea of an upper current blowing

in the opposite direction to the lower one has been described by Tyndall and other writers as an "invention" or "conjecture," but in justice to Henry it should be mentioned that he regarded the upper current as a condition naturally associated with a northeast storm on the east coast of this country. Moreover, in September, 1874, he ascertained by means of toy balloons that the upper current was blowing in the direction he anticipated and was in the direction of the maximum sound range.

Tyndall also criticized Henry's theory by saying that he did not understand how the sound wave could recross the hostile lower current. (Preface to Tyndall's Sound, 3d edition, pp. 19–20.) To meet this objection Mr. W. B. Taylor (**12**) has drawn a figure to illustrate the action of a compound wind in changing the direction of the sound rays, and this seems to make the matter clear.

Lord Rayleigh (**13**) has studied the reflection and refraction of sound at a horizontal surface, in crossing which the velocity of the wind changes discontinuously; it appears that if the upper velocity is the greater some of the rays will be totally reflected. He also remarks that sound moving to leeward over still water, being confined between parallel reflecting planes, diverges in two dimensions only and may therefore be heard at distances far greater than would otherwise be possible. Another possible effect of the reflector overhead is to render sounds audible which in still air would be intercepted by hills or other objects intervening.

When there is a strong upper current blowing in the opposite direction to the lower one, the preceding remarks are applicable to the case of sounds projected against the surface wind whether the bending downward of the sound by the upper current is supposed to be due to reflection or refraction.

In the mathematical theory of the refraction of sound in a windy atmosphere it is necessary to distinguish between the direction of a ray and that of the wave normal. The direction of the ray may be obtained geometrically as follows (**14**): Let P' be the position to which a point P would be carried in time δt if it moved with the velocity of the wind. Describe a sphere of radius $V\delta t$ round each such point P' where V is the local velocity of sound, and let Q be the point in which the sphere associated with P is touched by the envelope of all the spheres associated with the different points of the wave front. Then PQ is the direction of the ray at P. It follows from this construction that the ray-velocity is the vector sum of the wind-velocity and the local velocity of sound along the normal to the wave front.

This law can be obtained analytically by regarding the wave fronts as characteristics and the rays as bicharacteristics (**15**) of the partial differential equations of wave propagation in a windy atmosphere.

When the wind is blowing in one direction only, Fujiwhara (**16**) has shown that if viscosity, conduction of heat, and changes of composition are neglected, the sound motion can be derived from a velocity potential ϕ which satisfies the partial differential equation

$$\left(\frac{\partial}{\partial t}+u_1(z)\frac{\partial}{\partial x}\right)^2\phi=c^2\left(\frac{\partial^2\phi}{\partial x^2}+\frac{\partial^2\phi}{\partial y^2}+\frac{\partial^2\phi}{\partial z^2}+\frac{1}{\rho_1}\frac{\partial\rho_1}{\partial z}\frac{\partial\phi}{\partial z}\right)$$

The wind velocity $u_1(z)$ is parallel to the axis of x and is assumed to depend only on the height z above the earth's surface; ρ_1 is the mean density of the air at height z and c is the local velocity of sound.

Fujiwhara has endeavored to give a more physical meaning to the rays by regarding them as curves along which the energy of the sound motion can be supposed to flow. To reconcile this definition with the previous definitions of the rays he uses a particular solution of the partial differential equation and determines the flow of energy for the corresponding type of wave propagation. This particular solution is of the form

$$\phi=\psi(z)e^{\alpha}$$

where $\alpha\equiv iqt-lx-my+\int ndz$ is a solution of the differential equation of the characteristics, and q, l, m, are constants. With the aid of this expression for ϕ he verifies the above-mentioned law for the ray velocity and then proceeds to apply this law to determine the paths of the rays in the case of sound waves issuing from a point source.

This method is not rigorous, but the results which are obtained are fairly satisfactory, especially as they indicate the existence of a silent region and an area of abnormal audibility in the case when the wind velocity first increases and then decreases as z increases.

For our present purpose (**17**) it will be sufficient to consider the path of a ray which is in the plane of xz. The law for the ray velocity then gives

$$x=\int_0^z\frac{u_1(z)+cl}{cn}\,dz$$

where l, m, n, are the direction cosines of the wave normal. Let v be the actual velocity of the wave in the direction of the normal, then it follows from the geometrical method or from the differential equation of the characteristics that

$$v=lu_1+c.$$

Now the velocity of the trace of the wave front on a horizontal plane at which there is a change of wind velocity remains constant as we cross the plane, hence the law of refraction states that

$$\frac{v}{l}\equiv u_1+\frac{c}{l}\qquad\text{is a constant }\lambda.$$

Putting $m=0$, $n=\sqrt{1-l^2}$, $l=\frac{c}{\lambda-u_1}$, we find (**18**) for the path of a ray the equation

$$x=\int_0^z\frac{c^2+\lambda u_1-u_1^2}{c\sqrt{(\lambda-u_1)^2-c^2}}\,dz$$

When u_1 first increases with z and then decreases, a ray moving against the wind has a point of inflexion where $\frac{du_1}{dz}$ vanishes. To find the position of the vertex of the ray in this case we use a to denote $u_1(0)$ and b to denote the maximum value of u_1. Then for a ray moving against the wind the initial value of l is negative, and so if a is small, λ is also negative. The ray is symmetrical on the two sides of the vertex, consequently if R is the range on a horizontal plane through the starting point we have

$$R=2\int_a^b\frac{c^2+\lambda u_1-u_1^2}{c\sqrt{(\lambda-u_1)^2-c^2}}\frac{dz}{du_1}\,du_1$$
$$+2\int_b^c\frac{c^2+\lambda u_1-u_1^2}{c\sqrt{(\lambda-u_1)^2-c^2}}\frac{dz}{du_1}\,du_1$$

where both du_1 and $\frac{dz}{du_1}$ are negative in the second integral.

A point on the ground can be reached once, twice, or

not at all, according to the number of real roots which this equation in λ possesses.

To get a case in which the integrations can be carried out Fujiwhara assumes that

$$u_1(z) = k_1(z-h)+b \qquad z<h$$
$$= k_2(h-z)+b \qquad z>h$$

and shows that with certain values of the constants there is a minimum value of R and consequently a region of silence. For values of R a little greater than this minimum value there are two rays and consequently the sound may be heard twice. The case in which

$$u_1(z) = b-k(h-z)^2 \qquad b>kh^2$$

might be discussed with advantage, for in this case there is an upper current blowing in the opposite direction to the lower one. The integration can be effected with the aid of elliptic functions. An interesting mathematical problem which has not yet been solved is that of finding a distribution of wind velocity which will bring the rays which travel with the wind in a vertical plane xz to a focus on the ground.

The preceding theory is entirely geometrical and does not give any satisfactory information with regard to the intensity of the sound in the region of audibility. A rigorous mathematical investigation of the propagation of waves sent out from a point source can be made with the aid of the so-called fundamental solution of the partial differential equation. The existence of this solution has been established by E. Holmgren (**19**) and J. Hadamard (**20**). The solution may be derived from the corresponding solution for the ordinary equation of wave motion by a method of successive approximations.

§2. THE INFLUENCE OF INEQUALITIES OF TEMPERATURE.

Derham remarks in his "De Motu Soni":

> I have often observed in summer time, when the air has grown hot, that sounds appeared more languid than usual and were exceedingly weak in their impression on the ear; while in weather of another sort, especially in winter, if it happens to be freezing cold, the same sounds were much more piercing and shrill, and struck the ear more forcibly. Also, when the north or south east wind was blowing, however adversely, I have observed the sounds to be clearer and shriller than if the wind was blowing from contrary quarters, as Kircher also observed at Rome.

It has also been known for a long time that the sound of a distant waterfall can be heard more distinctly at nighttime than during the day. This phenomenon was explained by Humboldt as being due to the presence of inequalities of temperature during the daytime and their absence at nighttime (**21**). He supposed in fact that the inequalities of temperature produced inequalities of density, and that there were partial echoes at the limiting surfaces of rare and dense air.

This explanation is somewhat misleading, because in a gas of constant composition the velocity of sound is independent of the density, but varies as the square root of the absolute temperature (**22**). What is probably the true explanation was given by Osborne Reynolds, who showed that sound waves are refracted in passing through layers of air at different *temperatures*. Total reflection may of course occur in special cases.

If the temperature decreases upward, as it generally does during the daytime, sound rays are refracted upward, and an observer at some distance from the source may be left in a kind of sound shadow. A decrease of temperature of 1 degree Fahrenheit in 100 feet is sufficient to make a difference of about 1 foot a second in the velocity of sound and to produce a curvature equal to that of a circle 104,500 feet in radius. That the temperature gradient may be sufficient to produce quite an appreciable curvature of the rays is illustrated by an observation of Lord Rayleigh on a very hot day when the sound of a passing railroad train was almost inaudible at a distance of 150 yards (**23**). This curvature of the rays makes it possible for sounds to be heard at considerable distances above the earth when they are inaudible at a comparatively small horizontal distance. For instance, in their balloon ascents Flammarion and J. Glaisher have heard the sound of a train at heights of 8,200 and 22,000 feet, respectively (**24**).

At nighttime when the ground has become cool the temperature gradient is generally much smaller and may indeed be inverted owing to the presence of dew, consequently the audibility of sound is reduced very little by refraction.

In a letter to Nature, November 25, 1875 (**13, p. 67**), Dr. Schuster remarks:

> With regard to the question whether our better hearing at night is due to the absence of disturbing noises or to the cause suggested by Prof. Reynolds, I wish to remark that the Upper Himalayas are particularly free from any disturbing noises, yet the increase in our power of hearing at night is most marked.

Richard Townley wrote to Derham in 1704 to say that sounds are rarely heard as far at Rome as in England. Derham, wishing to test this point, caused an inquiry to be made in Italy. Some observations conducted by Joseph Averiani pointed to the conclusion that sounds can be heard as far in Italy as in England, but unfortunately the observations were made at nighttime while Townley's observations were most probably, judging from Derham's account, made in the daytime, and the direction of the wind was unrecorded. It is quite likely that the existence of a large temperature gradient in the latter case was the cause of the discrepancy.

The equation for the path of a ray when the refraction is due only to the temperature gradient is comparatively simple (**25**). The ray evidently lies in a vertical plane; and if θ is the angle which it makes with the vertical, then c cosec θ is unaltered by refraction. Hence

$$x = \int_0^z \frac{c\,dz}{\sqrt{a^2-c^2}}$$

where a is a constant for each ray. An interesting mathematical problem is that of finding a distribution of temperature such as will bring the rays in a vertical plane to a focus. If R is the constant range and h the height of a vertex of a ray we must have $a=c(h)$ and

$$R = 2\int_0^h \frac{c(z)dz}{\sqrt{[c(h)]^2-[c(z)]^2}}$$

for all values of h. This equation is satisfied by $c(z) = A\cosh\frac{\pi z}{R}$ where A is a constant (**26**). This law would correspond to an increase of temperature with z and could only hold for a short range of values of z.

A useful rule for comparing the refractive powers of wind and temperature is that a difference of 1 foot per second in wind velocity is nearly equivalent to a difference in temperature of 1° F. (**27**).

§3. THE INFLUENCE OF MOISTURE AND VARIATIONS IN THE COMPOSITION OF THE AIR.

The idea that sounds are reflected from clouds was developed by Tyndall (**28**), who supposed that invisible clouds, or a flocculent condition of the air, was produced

by streams of water vapor rising from the sea. The aerial or ocean echoes discovered by Henry (29) were attributed by Tyndall to the presence of these invisible clouds, and other abnormal effects were explained as being due to the acoustic opacity of the atmosphere. Tyndall supported his theory by a number of interesting experiments made in the laboratory, but observations which have been made under actual conditions do not seem to favor his views. For instance, in a balloon ascent Flammarion noticed that when the balloon was in the midst of a cloud the sound of a band increased in intensity and the band seemed quite near (30). Again, when Henry tried to obtain an echo from a visible cloud the effect was imperceptible (31).

Henry does not seem to have been satisfied with Tyndall's explanation of the silent region and made some experiments to see if the sound of a fog signal could be intercepted by an acoustic cloud. He used the method of reciprocal observations and showed that sometimes a sound produced at A might be heard at B, while a similar sound produced at B could not be heard at A. Such a failure of reciprocity is probably due to the wind (32).

Henry suggests as a possible explanation of the echo that in the spreading out of the sound from the siren some of the rays take such curved paths that they are reflected back from the sea. A peculiarity of the echo is that it seems to be produced only by signals in which a direction is given to the sound and appears to come from a point on the horizon in the horizontal projection of this direction (33). When Henry ordered the siren to be fixed so that the sound was directed vertically upward the echo appeared to come from the whole of the horizon. It is still thought that no satisfactory explanation of the echo has been given (34).

When a train of waves in a heterogeneous medium is produced by a local disturbance which lasts for a finite interval of time a portion of the medium does not generally remain undisturbed after the wave has passed over but a residual disturbance, which may be of an oscillatory character, is left behind. It is possible that the first maximum of this residual disturbance may correspond to the aerial echo. If this residual disturbance is due entirely to reflections caused by the inequalities of the medium this explanation is practically the same as Tyndall's, but there may be a residual disturbance when the medium is isotropic, as, for instance, when the propagation takes place in two dimensions (35). The propagation of sound through a medium of varying properties has been studied with special reference to the question of reflection by Lord Rayleigh (36) and J. W. Nicholson (37); the latter concludes that Tyndall's explanation of his own experiments is a very possible one. The propagation of sound in a heterogeneous nonabsorbing fluid has also been discussed recently by M. Brillouin (38), who considers the question of dispersion and the variation of amplitude. He shows also that the flow of potential energy does not remain constant along a tube of orthogonal trajectories of the wave fronts (39).

Nicholson says:

> Tyndall's acoustic clouds were regarded by him as being mainly due to the presence of an excess of aqueous vapor in some parts of the atmosphere. Now, moist air has a greater power of radiating heat than dry air, and the consequent "stifling" of the sound passing through very moist air (40) may be appreciable, although in air under ordinary conditions the effect is negligible.
>
> Tyndall does not give a definite idea of the nature of the action of an acoustic cloud, which may act, for the purposes of his theory, by stifling the sound, by scattering, or by reflecting it back to its starting point. Probably the first two effects both play their proper parts. Moreover, as we have shown, the backward reflection when sound enters such a dissipative medium tends to lose its periodicity, and to be independent of the reflecting medium when the dissipation exceeds a certain limit.

The following observation mentioned by Pasquay (41) is of some interest. A whistle was heard at a place 12½ kilometers away from the source of sound and separated from it by two ridges of hills. As this occurred just before rain set in the phenomenon was attributed to the reflection of the waves of sound at the upper layers of air which was saturated with moisture. An upper current of wind or an unusual distribution of temperature might also have produced this effect.

A refraction of sound may also be produced when the percentage of water vapor in the atmosphere varies with the height; for, as Reynolds pointed out, an increase in the amount of water vapor lowers the density and so increases the velocity of sound. An excess of water vapor overhead would produce a downward refraction of the rays, but the curvature would be very small.

H. Mohn (42) and W. R. Livermore (43) have discussed the refraction of sound under the combined action of wind, temperature, and humidity. There is some uncertainty, however, about the exact effect of humidity because it is not known how the ratio of the specific heats varies with the amount of water vapor present in the air. The vapor of γ for dry air is about 1.4 and for water vapor about 1.3. Now Capstick (44) has given a formula

$$\frac{P}{\Gamma-1}=\sum\frac{p_s}{\gamma_s-1}, \qquad P=\sum p_s$$

for determining the ratio Γ of the specific heats of a mixture of gases when the ratios γ_s and the partial pressures p_s of the components are known. At present it is unknown whether this formula is applicable to a mixture of air and water vapor. Some experiments ought to be made to decide this point.

To account for the areas of silence and abnormal audibility observed at the time of some recent dynamite and volcanic explosions, G. v. d. Borne (45) has introduced the idea of an effect due to the presence in the upper atmosphere of an isothermal region and of air composed mainly of hydrogen. By using Dalton's law for mixed gases, he has calculated the velocity of sound at different heights and determined the paths of the rays. His computed range of the silent regions agrees very nearly with the observations. Borne also considers that there may be a total reflection of rays at a lower boundary of the "hydrogen atmosphere." It is unlikely, however, that there is anything like a sharp discontinuity in the density of the air (46).

Quervain (47) and Fujiwhara (48) are of the opinion that the abnormal range of the sound produced by the dynamite explosion on the Jungfrau railway was due chiefly to the wind and not to the presence of the hydrogen atmosphere. Fujiwhara has made an elaborate study of the sound phenomena associated with the eruptions of Mount Asama and the diagrams in his memoir indicate very clearly the action of the wind (49). Abnormal phenomena relating to the audition of sound have been noticed during the eruptions of Cotopaxi and Krakatoa. There has been some difference of opinion as to the effect of fog on the propagation of sound. Derham remarks:

> A like uncertainty obtains with regard to clear and foggy air. In rainy and damp weather I have often observed that sounds are blunted and that after torrential rains they acquire the greatest strength, as Kircher observed at Rome. But the contrary also often happens. * * * But as regards *thick fogs*, it is certain that they are dampers of sound in the highest degree. For sounds then seem to be for the most part very weak and blunted—a fact which very certainly proceeds

from the interposed vapors and thick particles which compose fog. I have likewise observed the same concerning snowy weather. For when fresh snow has fallen on the ground sounds straightway grow dull; but when its surface has been covered with ice, the sounds suddenly become more acute, and I then have heard bells ringing and cannon booming just the same as if there was no snow on the ground.

This statement of Derham's seems to have given rise to the idea that fog is always prejudicial to the propagation of sound. Although this was denied by Desor (50), the idea was generally accepted until the time when systematic experiments were made with fog signals. Thus Reynolds says (51):

That sound does not readily penetrate a fog is a matter of common observation. The bells and horns of ships are not heard so far during a fog as when the air is clear. In a London fog the noise of the wheels is much diminished, so that they seem to be at a distance when they are really close by. On one occasion, during the launch of the *Great Eastern*, the fog was reported so dense that the workmen could neither see nor hear.

The experiments of Henry, Duane, and Tyndall have shown conclusively that sound can generally be heard quite distinctly in a fog; indeed, the passage of sound through a fog is usually favored by the homogeneous condition of the atmosphere which is the usual concomitant of foggy weather. Some kind of reflection may, however, take place when sound waves pass from clear air into a fog, while if the sound is produced in the fog, its intensity may be greater than in clear air owing to the greater density of the fog.

In a description of some remarkable noises, T. McKenny Hughes (52) remarks that the propagation of the sound is affected by fog. He says that the noises are probably produced in some way by the tide at Morecambe Bay, and compares them with the "barisàl guns." In this case, however, it may be that the sea is comparatively calm when there is a fog, so that the latter hinders the production of the sound rather than its propagation. The propagation of sound through a foggy atmosphere has recently been studied mathematically with the aid of the hydrodynamical equations for the motion of a viscous fluid. C. J. T. Sewell (53) treats the drops of water as minute spherical obstacles and assumes that the volume occupied by the suspended drops is small compared with the total volume of the fog. The first calculation was made on the hypothesis that the drops of water do not move. Sewell then found that if the diameter of each drop is about 0.02 mm., and there are 10^3 drops per cubic centimeter, then the fog does not interfere appreciably with the propagation of sound, but if the diameter of each drop is about 0.002 mm., a fog of the same density would contain 10^6 drops per cubic centimeter and the sound would be damped very quickly by the fog. In a second calculation, made at the suggestion of Prof. Larmor, the drops were supposed to be capable of vibrating with the surrounding air. It was then found that a fog in which the drops have diameters as small as 0.002 mm. should not interfere appreciably with the propagation of sound. Sewell also concluded that when the wave length of the sound is very great, or when the obstacles are extremely minute, a drop vibrates with the surrounding air.

These calculations were made on the assumption that the sound was produced continuously by the source. In the case of sounds of short duration the results may be slightly different.

Duhem (54) has studied the propagation of such sounds through a viscous medium and has shown that a wave of discontinuity, in the sense in which the term is usually used by French writers, can not be propagated at all. To show that disturbances can be propagated, however, Duhem has considered a class of waves which he calls "quasi-waves." At the front of such a wave at least one of the partial derivatives $\left(\frac{\partial u}{\partial x}, \frac{\partial u}{\partial y}, \frac{\partial v}{\partial x} \cdots \frac{\partial w}{\partial x} \cdots\right)$ of the component velocities u, v, w, is supposed to undergo a rapid change in crossing a layer of small thickness ε, so that if $\frac{\partial u}{\partial x}$ is one of the derivatives in question the difference between the values of $\frac{\partial u}{\partial x}$ on the two boundaries of the layer is a finite quantity which is not small. Duhem then shows that a "quasi-wave" can only be propagated in a viscous fluid when the thickness ε of the thin layer of transition is at least of the same order of magnitude as the coefficient of viscosity μ. When μ is very small the laws of propagation of these quasi-waves are practically the same as those of waves in a perfect fluid. The case in which the medium is homogeneous has been studied more fully by Le Roy (55) who has obtained a general solution of the partial differential equation

$$\left(\lambda\frac{\partial}{\partial t}+a^2\right)\Delta\phi-\frac{\partial^2\phi}{\partial t^2}=0$$

on which the motion depends. He finds by considering a particular case that the phenomena of propagation are sufficiently clear at the start but that some time after the production of the disturbance the thickness of the quasi-wave increases and becomes more and more badly defined, so that the phenomenon of propagation ends by becoming very vague. He concludes also that in the general case when there is initially both displacement and velocity, it is chiefly the disturbance due to the velocity that causes the flow of energy. In a rigorous discussion of the propagation of sound, the conduction of heat ought also to be taken into account for its effect is of the same order of magnitude as that of viscosity (56).

FOG SIGNALS.

Derham suggests at the end of his memoir that gunshots might be used to enable sailors to ascertain by means of the sound the distance of a ship from another ship or from the land. He does not, however, suggest that the signals should be used in a fog, probably on account of his belief that the sound would be rapidly stifled. The idea that fog tends to intercept or modify sound in its passage through the air led to the consideration whether water itself might not be employed as a medium for the transmission of fog signals, and in 1851 Charles Babbage recommended that some experiments should be made (57). Submarine bells are now used for signaling on many ships. In 1854 some experiments on different means of producing sounds for the purposes of fog signals were made by the engineers of the French lighthouse department, and in 1856 and 1863 similar experiments were started in England and the United States (58).

The extensive observations that were carried out by the United States Lighthouse Board to determine the penetrating powers of the different fog signals under various atmospheric conditions have revealed the existence of some very curious phenomena which have been observed over and over again in subsequent experiments (59).

Chief among these are the alternate regions of silence and audibility discovered by Gen. Duane. Joseph Henry attributed these to the presence of an upper wind blowing in the opposite direction to the lower one, but this can not always be the cause of the phenomenon because regions of silence and abnormal audibility have been noticed in apparently clear weather and at no great distance from the source. The areas of silence around a given fog signal are generally constant in their general position but variable in actual position (60). It seems almost impossible to predict beforehand whether the signal will be heard at a given place or not, and many accidents have occurred at sea owing to the inaudibility of a fog signal which was being sounded as usual.

Tyndall (61) and F. E. Fowle (62) have suggested that the regions of silence and abnormal audibility are due to the interference of the direct rays of sound with those reflected from the surface of the sea or ground, but Lord Rayleigh (63) does not seem to be satisfied with this explanation. Indeed, if the silence were due to interference, it should be possible to recover the sound by ascending the mast of a ship, and the position of a silent region should depend on the pitch of the sound.

The principal fog signals that have been used are the siren trumpet (64), an improved form of siren invented by Mr. Adolphus Brown, of New York, the Daboll trumpet or reed horn invented by Mr. C. L. Daboll and improved by Prof. Holmes, steam whistles, guns, bells, and gongs. Experiments have indicated that the siren is the most powerful and effective signal; the reed horn, although inferior in power, is suitable for situations of secondary importance. At first the siren was blown by steam, but compressed air was found to give better results, probably on account of its greater density (65).

A cylindrical form of siren invented by Slight is now generally used (66), but in Canada a modification of the siren, called the diaphone, is widely employed. Besides the instruments already mentioned there is the whistling buoy, invented by Mr. Courtenay, and explosive signals, such as guncotton. A whistling buoy is often placed in regions where the fog signal has not been heard. Sometimes a double horn or siren is used so as to cover a greater range and avoid the occurrence of silent regions. Lord Rayleigh has suggested that better results might be obtained by using a trumpet with an elliptical mouth (67). This device was tried with success in some experiments that were made in 1901 at St. Catherines Lighthouse in the Isle of Wight (68). The Clyde Navigation Trust has quite recently made some experiments with fog guns charged with gas and an apparatus for firing the guns by means of electric waves. It is thought that such guns can be placed with advantage on dangerous rocks and that the wireless system will remove difficulties which have hitherto been insurmountable.

In spite of the excellence of fog signals disasters occur frequently at sea, and the recent wrecks of the *Titanic* and *Empress of Ireland* point to the conclusion that greater precautions ought to be taken. Sometimes a fog signal can be heard distinctly, but it is difficult to tell from which direction the sound is coming. Mr. Della Torre, of Baltimore, has invented an instrument for overcoming this difficulty and believes that it can be used successfully to locate an iceberg by means of an echo.

Other methods of detecting the presence of an obstacle are sometimes available; for instance, it is well known that many fogs are near the surface of the ocean, and a sailor at the masthead as a lookout is all that is needed. The approach of an iceberg can often be detected by a change in the temperature of the water, and Prof. H. T. Barnes, of Montreal, has devised a sensitive instrument to record such a change.

THE SOUNDS PRODUCED BY BOLIDES OR METEORS.

The noises heard during the fall of a meteor in the Lower Pyrenees, on September 7, 1868, are described by Flammarion as follows (69):

> The disappearance of the meteor was preceded by an explosion. This was followed by a continuous noise like the distant rolling of thunder, then by three or four detonations of extreme violence, which were heard at points distant 50 miles from each other. Immediately after these detonations the inhabitants of Sanguis-St. Étienne heard a hissing noise, like that made by red-hot iron when it is plunged into water, then a dull sound, indicating the fall of a solid body to the ground.

On Christmas Eve, 1873, a remarkable meteor was seen from Washington, and the phenomena relating to it were investigated by Cleveland Abbe (70) and some other members of a special committee. Again there was an explosion followed by a rumbling. The reporters considered the noises to be due not to a single definite explosion of the meteor, but to the concentration at the observer's ear of the vast volume of sound emanating

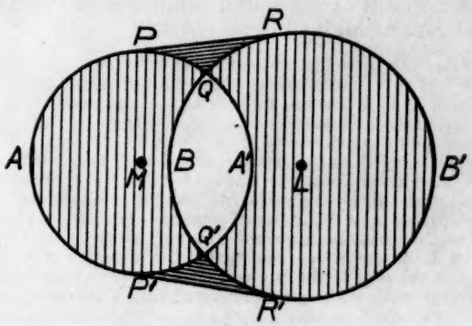


FIG. 1.—Regions about a meteor path.

almost simultaneously from a large part of the meteor's path, being in that respect not dissimilar to ordinary thunder.

This meteor probably described its entire visible path of about 120 miles in three or five seconds; consequently it traveled with a velocity much greater than that of sound. Now, when a body moves with a very great velocity and produces sound for a short interval of time, the elementary spherical waves that issue from its various positions where the sound is produced, have at any instant a real envelope and the disturbance is of a different nature in different regions of space. This may be illustrated by figure 1.

The disturbance which is supposed to be due to the sounds emitted by the friction of the meteor against the air while it describes the path LM is confined within the shaded region. Within the regions PQR, P′Q′R′ the sound is concentrated; there are, in fact, two elementary spherical waves through each point. Within the regions PAP′Q′BQ, QRB′R′Q′A′, the disturbance differs very little from an ordinary wave of sound, but there is a difference in pitch in the two cases, owing to the Doppler effect. The region of concentration is confined to the neighborhood of a belt or truncated portion of a cone of revolution having LM as axis. This belt is the front surface of a sound bore. At a point of this belt sounds

issuing from two consecutive points of the meteor's path reinforce one another. At points of the region of concentration not at the front of the bore the sound is due to elementary waves issuing from different points of the meteor's path, and these may or may not interfere (**71**).

E. Mach thinks that the sound bore that is produced by a projectile traveling with a velocity greater than that of sound is responsible for the explosive sounds that are sometimes heard when a great meteor travels through the air. As I understand it, Abbe's theory of 1877 is an attempt to explain how the sound bore is produced.

The bore produced by a projectile moving with a very high velocity through the ordinary air has been photographed by Mach and much more successfully by C. V. Boys (**72**). It appears that a bullet traveling at a speed of 2,000 feet per second is accompanied by two quasi-conical wave sheets having the same axis. The angle of the cone is such that the velocity of the bullet resolved normal to the wave surface is equal to the velocity of sound in the gas in the condition as to pressure, density, etc., which obtains at the position at which the normal is drawn. The curvature of the generating lines of the surfaces indicates that the condition of the surrounding air is changed for a distance which is considerable in comparison with the dimensions of the bullet (**73**).

In an account of the sound produced by the motion of a bullet Mr. A. Mallock says (**74**):

> Soon after the introduction of modern rifles, which give their projectiles a velocity much higher than that of sound, I noticed that when standing in a position in front of the gun and not far from the line of fire, the sound seemed to come, not from the firing point, but from some point considerably in advance of the gun. The natural explanation seemed to be that the sound thus heard was not that of the explosion itself, but was caused by the wave surface which is generated in the air by the projectile, moving at a velocity higher than sound. It is clear (if the source of sound is due to the wave caused by the projectile) that the apparent direction of the sound will be the normal to the wave-surface, and that if the direction of this normal is known, the velocity of the projectile, at the time that that particular portion of the wave-surface was generated which ultimately reaches the observer, can be calculated.

In the case of a meteor a direct application of this principle is beset with difficulties, owing to the refraction of the sound waves by the wind and temperature gradient.

The Editor having suggested that I should write this review, tells me that Dr. P. J. Nutting, formerly of the United States Bureau of Standards, has assisted him in devising a meteor-recorder by means of which the exact time, location, and velocity of a meteor may be determined. A number of systematic records obtained with the aid of an instrument of this kind would be of great help in clearing up some of the difficulties connected with the sounds produced by great meteors.

Descriptions of the sounds heard by different observers after the fall of a meteor, have been collected on several occasions (**75**) and give a useful qualitative description of some interesting phenomena, but it is desirable that quantitative methods should be used as far as possible.

It is difficult to explain the repeated detonations that are sometimes heard, by the simple bore theory. It is quite likely that echoes arise in some way, either by a total reflection of sound by the wind or a layer of air saturated with moisture or from the unknown cause to which the aerial echo is due.

The fact that the sounds are heard so distinctly, although the meteor is at a great distance from the observer, is attributed by Reynolds to the upward curvature of sound rays due to the refraction by wind and temperature. Observations in balloons point to the correctness of this theory, as sounds are heard very distinctly at a considerable distance from the earth.

NOTES AND REFERENCES.

(1) **William Derham** (1657–1735), English theologian and man of science, was pastor of Upminster in the county of Essex. An account of his researches was published in Latin (Phil. tr., R. soc., London, 1708, **26**). A copy of an English translation by Rev. Dr. J. C. Welling is in the library of the U. S. Weather Bureau. Dr. Welling has also given a brief account of Derham's work in a paper published in the Bulletin of the Philosophical Society of Washington, 1883, **5**, p. 39.

(2) **Averiani** was a professor at the University of Pisa. He had been asked by the Grand Duke to make some experiments that would furnish answers to some questions which had been raised by Derham.

(3) Annales de chimie, 1816, **1**, p. 177.

(4) **Henry, Joseph.** Researches in sound. Smithsonian rept., 1878. This volumes contains a number of diagrams showing the ranges in different directions.

(5) Proc., Royal soc., London, 1874, **22**, p. 531.

(6) Report of the British Association for advancement of science, 1874: Math. and phys. papers, **4**, p. 110. The above condensed version of Stokes's theory is taken from Rayleigh's "Sound," v. **2**, p. 132. Stokes also considers the form of the wave front. This will be discussed more fully when we come to the mathematical theory.

(7) The reports on these experiments date from 1852 when the Lighthouse Board was organized. Henry's reports of 1874, 1875, 1877, and Maj. W. R. Livermore's report of 1894, are of special interest. Henry's experiments were commenced in 1865. They are summarized in Smithsonian report, 1878, and in "Scientific writings of Joseph Henry," **1**, p. 364–510.

(8) *See* **Beazeley, Alexander,** "On coast fog signals," a lecture delivered at the Royal United Service Institution in 1872.

(9) Bull., Phil. soc., Washington, 1875, **2**, p. 59.

(10) **Henry's** Researches, p. 550.

(11) **Henry's** Researches, p. 494. In this case the surface wind was blowing a gale toward the fog whistle and the sound was heard further against the wind than in other directions. An account of some abnormal phenomena of sound noticed during the experiments with fog signals was given by Henry at a meeting of the Philosophical Society of Washington in 1872. Professor Tyndall was present at that meeting. Shortly afterwards Tyndall described some remarkable phenomena he had noticed during his own researches. *See* Bull., Phil. soc., Washington, 1872.

(12) Amer. jour. arts and sci., New Haven, 1876.
Henry's Researches, p. 513.
Livermore's report, 1894.

(13) **Rayleigh.** Theory of sound. **2**, p. 133. The theory is corrected and explained more fully in **Lamb,** "Dynamical theory of sound," p. 220.

(14) **Lamb, H.** Dynamical theory of sound. London, 1910. p. 220.

(15) **Hadamard,** Propagation des ondes. Paris. 1903.

(16) **Fujiwhara** *in* Bull., Central meteorol. obs'y., Japan, Tokyo, 1912, **2**, no. 1. Proc., Tokyo math.-phys. soc., (2) **6**, no. 9, p. 132.

(17) Fujiwhara obtains equations for the path of a ray that starts in any direction.

(18) **Fujiwhara** *in* Jour. meteorol. soc. Japan, Tokyo, 1911, **30**, no. 8, p. 195.
Fujiwhara *in* Bull., Central meteorol. obsy., Japan, Tokyo, 1912, **2**, no. 1, p. 47.

(19) **Holmgren, E.,** *in* Arkiv for matematik och fysik, 1903, 1.

(20) **Hadamard, J.,** in Annales, École normale, (3) 1904, **21**, p. 535.

(21) **Tyndall,** Lectures on sound. 2d ed. 1869. p. 18–19.

(22) Provided the temperature is not high enough to affect the ratio of the specific heats.

(23) Proc. Royal soc., **A86,** 1911, p. 207.

(24) **Flammarion, C.** The atmosphere. (English trans.) London, 1873. p. 80.

(25) **Rayleigh.** Sound. **2**, p. 131.
Lamb. Dynamical theory of sound. London, 1910. p. 217.

(26) The equation is an integral equation of Abel's type and may be solved by a well-known method.

(27) *See* **Livermore,** Report to the Lighthouse Board.

(28) **Tyndall,** Phil. trans., 1874; Sound, 3d ed., chap. 7.

(29) **Henry, Joseph.** Researches in sound. pp. 516, 553, 558.

(30) **Flammarion, C.** The Atmosphere. London, 1873. p. 81.

(31) **Henry, Joseph.** Researches in sound. p. 530.

(32) Tyndall quotes a famous case of a failure in reciprocity when the wind was slight. (Sound, 3d ed., p. 432.) This case has been discussed by Reynolds in Phil. trans., 1876, and in Scientific papers, **1**, p. 157.

(33) *See* Henry and Reynolds, loc. cit.

(34) *See* for example the article "Lighthouses" in Encyclopedia Britannica.

(35) **Lamb, Horace.** Hydrodynamics. 2d ed. Cambridge. 1895. pp. 282, 502.

(36) **Rayleigh.** Theory of sound. **2**, p. 78; Proc. Roy. soc., 1911, **A86**, p. 207.

(37) **Nicholson, J. W.** Proc. Royal soc., 1908. **A81.**

(38) **Brillouin.** Comptes rendus, Paris, 1913, Dec. 8.

(39) In the case of propagation through a windy atmosphere I have not succeeded in proving that the flow of energy at the front of a wave is in the direction of the ray. The rate of change of momentum seems to be in this direction.

(40) **Stokes** *in* Phil. mag., London, April 1851. "Math. & phys. papers," v. 3, p. 142.

(41) **Pasquay** *in* Prometheus, 1903, **14**, p. 384.

(42) **Mohn, H.**, *in* Annalen d. Hydrographie, etc., 1892, 1893, 1895.

(43) **Livermore, W. R.** Report to the Lighthouse Board.

(44) **Capstick**, *in* Phil. trans., Royal soc., London, 1894, A., p. 1.

(45) **von der Borne, G.**, *in* Physikal. Ztschr., 1910, p. 483.

(46) **Humphreys, W. J.**, *in* Bull. Mt. Weather obsy., Washington, 1911, **4**.

(47) **Quervain**, *in* Annalen, Schweiz. meteorol. Zentralanst., 1908.

(48) **Fujiwhara**, *see* (16).

(49) The conditions prevailing during the eruption of Mount Asama on January 6, 1911, and of Bandaisan correspond to those postulated by Henry. *See* first reference under (16), p. 41–44.

(50) **Desor**, *in* Fortschritte der Physik, 1855, **11**, p. 217.

(51) **Reynolds**, *in* Proc. Manchester lit. & phil. soc., 1873–4; Reynolds, Scientific papers, **1**, p. 43.

(52) **Hughes, T. McKenny**, *in* Nature, London, 1895, Nov. 14. Many other remarkable noises are described in letters to "Nature" in answer to a request by Sir George Darwin (Nature, London, 1895, Oct. 31) for information regarding the "barisàl guns" and "mistpoeffers." The former are described in the Proceedings, Royal Asiatic soc. Bengal, 1899, p. 199.

A number of papers on remarkable noises will be found in the Monthly Weather Review, Washington, vols. **23, 26, 31, 35**, between 1895 and 1907.

(53) **Sewell, C. J. T.**, *in* Phil. trans., 1911, **A210**.

(54) **Duhem**, *in* Annales de Toulouse, 1901–1904, (2), **3–5**.

(55) **Le Roy**, *in* Comptes rendus, Paris, 1913, Ap. 21, 28, Je. 2; 1914, Ap. 27.

(56) This was first remarked by Kirchoff. *See* **Lamb**, Hydrodynamics, 2d ed., Cambridge, 1895, p. 587.

(57) Report of the U. S. Lighthouse Board, 1882, p. 163. In the Report of the British Association for the Advancement of Science for 1861, Prof. Hennessy discussed the subject and referred to some experiments made by Colladon on the Lake of Geneva in 1826.

(58) For the history of the subject, see: **Beazeley, A.** On phonic coast fog signals. Proc. Instit. civil engin., 1870–71, **32**, pt. 2.

(59) *See* **Henry's** Researches, p. 481, 489, 493, 497, 536, 546, 549; **Tyndall**, Sound, p. 298.

Johnson, A. B., *in* Bull., Phil. soc., Washington, 1881, **4**, p. 135; ibid., 1883, **5**, p. 23.

Livermore, Report, 1894; Nature, London, 1895, Aug. 8, p. 347; Knowledge, London, 1901, June.

(60) According to Price Edwards (Nature, London, 1902, May 29) the silent areas do not occur frequently. Mr. Della Torre suggested to me that they were due to the breaking up of the sound by local eddies or whirlwinds.

(61) **Tyndall**, *in* Proc. Royal soc., London, 1882, **34**, p. 18.

(62) **Fowle, F. E.**, *in* Nature, London, 1895, Nov. 7.

(63) **Rayleigh**, *in* Proc. Royal instit., London, 1902, **17**, p. 1; Nature, London, 1902, **66**, p. 42; "Scientific papers," **5**, p. 1.

(64) Tyndall gives a diagram of this siren trumpet in his "Sound." Numerous suggestions with regard to the most suitable pitch and location of a fog signal are given in Henry's Researches, in Livermore's report, and in the article "Lighthouses" in the Encyclopedia Britannica.

(65) **Henry**, Researches, p. 480; **Ribière**, International maritime congress, London, 1893.

(66) Encyclopedia Britannica, article "Lighthouses."

(67) **Rayleigh**, Scientific Papers, **5**, 1. A mushroom-shaped trumpet is often used on lightships.

(68) An account of these experiments on the Isle of Wight is given in Nature, London, 1902, May 29.

(69) **Flammarion.** The Atmosphere. London, 1873, p. 175.

(70) **Abbe, Cleveland.** Report, *in* Bull. Phil. soc., Washington, 1877, p. 139; **Peck, H. A.**, *in* ibid., 1907, **35**, p. 447.

(71) The possibility of interference was pointed out by E. Mach & B. Doss, and was regarded by them as an objection to C. Abbe's theory. (*See* Berichte, K. k. Akad. d. Wissensch., math.-physikal. Kl., IIA, Wien, 1893, **102**.)

(72) **Boys, C. V.**, *in* Report, Brit. assoc. adv. sci., 1892; Nature, London, **47**, p. 415–420, 440–446.

(73) **Mallock, A.**, *in* Proc. Royal soc., 1907, **A79**, p. 262. Boys's experiments have also been discussed by **Stokes**, Memoir and scientific correspondence, **2**, p. 337–357.

(74) **Mallock, A.**, *in* Proc. Royal soc., London, 1907, **A80**, p. 110.

(75) See, for instance, **G. von Niessl** *in* Berichte, K. k. Akad. d. Wissensch., math.-physikal. Kl., IIA, Wien, 1896, **105**, p. 23, and 1912, **121**$_2$, p. 1883.

In the case of the great meteor of September 23, 1910, O. Michalke heard about a dozen detonations of different strengths, two or three being very loud. Another observer heard a detonation like that of a distant gun followed immediately by a roll in the clouds, the sound appearing to come from an approaching region. The noise was quite different and much louder than that of thunder.

The noises mentioned by J. Burton Cleland and H. L. Richardson in letters to Nature, London, 1908, June 4 and August 27, were perhaps due to a meteor.

THE MECHANICS OF ATMOSPHERIC AIR WITHIN CYCLONES AND ANTICYCLONES.[1]

[Communicated to the International Meteorological Congress at Chicago, August, 1893.]

By Geh. Hofrat Prof. Dr. MAX MÖLLER.

[Dated Herzogl. Techn. Hochschule, Braunschweig, May, 1893.]

A. THE DIRECTION OF ROTATION AND THE DISTRIBUTION OF PRESSURE.

By a cyclone we understand a whirling mass of air whose rotation, in the Northern Hemisphere, is accomplished in a direction opposite to that of the movement of the hands of a watch; by an anticyclone, on the other hand, we mean a whirling mass of air whose rotation, in the Northern Hemisphere, corresponds to the movement of the watch hands.

In the Southern Hemisphere the conditions are reversed. In the center of the cyclone low pressure always prevails; hence the cyclone is often spoken of briefly as a depression. In the center of the anticyclone high atmospheric pressure generally prevails; hence this is often called a high pressure or maximum. However, there are also anticyclones with low pressure in the center; but this occurs only when the diameter of the anticyclone is small relatively to the strength of the wind (compare section 15 hereafter).

In the ultimate analysis the movements of the atmosphere are almost exclusively produced by differences of temperature; they are, however, so affected by the influence of the inertia of moving masses of air and so hindered by friction due to mutual mixing of masses of air that a study of these numerous relations must first be undertaken in detail before we can successfully proceed to the explanation of such complex natural processes.

According to the theoretical investigations of our master, the late Prof. Ferrel, in the field of the discussion of atmospheric whirlwinds, we have to distinguish many kinds of cyclones and anticyclones.

B. THE THREE KINDS OF CYCLONES.

(a) We have to mention first the cyclone with descending air and a cold center as it is presented to us in general in that whirl which surrounds the temperate, and partly also the cold zone, and produces the westerly trade, namely, the strong west winds of the "roaring forties."

Other examples of depressions with descending air currents have also been observed. Thus, for example, on April 13, 1893, two depressions of this kind rested upon western Russia and the Baltic Sea, respectively. The presence of descending air in this depression or cylone was shown first by the great dryness of the air and by the absence of any considerable precipitation, especially by the fact that clear sky prevailed in the region of the strongest winds; second, and most important of all, the circumstance that at more than 20 European stations at that time the northwest and northeast winds showed no inflow into the depression, but moved parallel to the isobars or passed from the region of feeble pressure over to that of higher.

[1] The present paper was prepared for publication in 1901, but publication has been delayed for the reasons stated in the REVIEW for February, 1914, 42: 93.

But these depressions were not wholly without cloud and precipitation, since by reason of friction on the rough ground the whirls in the lowest strata were enfeebled, and hence introduced a local flow of air into the depression and its ascent of air directly at the earth's surface up to moderate or at least slight altitudes. At the same time cloud and precipitation occurred in those portions of the whirl where for other reasons the air possessed a smaller wind velocity.

(b) Second must be mentioned those regions of cyclonic motion with decided descending currents that are distinguished by abundant precipitation and possess a more sharply defined center than the depressions mentioned under (a) and which when they show a small diameter can assume the form of tornadoes or waterspouts.

(c) Third, we mention the cyclones that have on one side ascending currents of air and on the other side descending.

C. THE THREE KINDS OF ANTICYCLONES.

(a) The anticyclones having *descending air currents* and high pressure in the center surrounded by isobars as nearly circular as possible, are surrounded by the ascendind air currents of cyclonic areas of depression whose masses of air flow overhead to the anticyclone in the anticyclonal manner.

(b) The anticyclones with *ascending air currents* rarely occur as depressions, but this can occur when they have small diameters.

More frequently anticyclones with ascending currents occur as areas of high pressure, and especially is this the case at the beginning, when the development of the anticyclones is in its first stages. In such cases the air flows anticyclonally toward the anticyclone from any depression in the lowest or median altitudes.

(c) The anticyclones with air currents *ascending on one side and descending on the other* but horizontal at the summit. An anticyclone of this character forms a zone of high pressure between two cyclones, one of which has ascending and the other descending currents of air at the center.

D. CURRENTS OF INFLOW AND OUTFLOW.

Those currents are designated as feeders that bring air to a cyclone or anticyclone. Those currents are designated as outflows that carry air away from the region under investigation. A storm that represents a region of outflow forms also a feeder for the neighboring regions. By means of the streams of inflow and outflow the moment of rotation of the whirling region becomes a cyclone or an anticyclone.

E. THE MOMENT OF ROTATION OF A MASS OF AIR IS INDEPENDENT OF THE MAGNITUDE OF THE GRADIENT.

In the following text the moment of rotation of any mass of air is taken with reference to the center of curvature of the isobars and to a system of axes at this central curvature and which move with the rotation of the earth's surface; hence we are ivestigating not absolute but relative air velocities, that is to say the winds.

It can not be made too clearly prominent that every whirl, whether of the cyclonal or anticyclonal form, when in contact with the rough surface of the earth loses some of the moment of rotation proper to it and that the loss thus arising can in no way be balanced by the work done by the gradient force.

The total work done by friction in the direction of the rotation of a whirl, or abstracted from the whirl, is expressed in the contrast of the amounts of the moment of rotation of the feeders and the outflows as soon as a steady condition of motion has been established. The rate of loss of moment of rotation per second induced by friction is equal to the difference of the quantities of the moment of rotation of the streams with reference to the center of the whirl, if we consider this latter as the center of the rotation.

If now the moment of rotation of the inflow, namely, the feeding streams, is of such eminent importance to the whirling system that it decides whether a whirl shall be a cyclone or an anticyclone; and if furthermore the work of the frictional resistances at the rough surface of the earth partially and steadily diminishes this moment of rotation, then we see the importance of those studies that have to do with these relations and with the motion of the upper currents of air.

Our subsequent investigations of these matters assumes a knowledge of certain auxiliary theorems of the theoretical doctrines of motion or dynamics which will now be enumerated and occasionally explained by applications.

F. THE MOMENT OF ROTATION WITH REFERENCE TO THE GRADIENT FORCE AND THE FRICTION.

AUXILIARY THEOREMS, GROUP I.

(1) The moment of rotation of any mass is not changed by the work done by the force due to the radial gradients. The demonstration of this theorem follows directly from the recognition of the fact that gradients are only the interior tension of the whirling system by which neither the center of gravity of the system is altered nor is the moment of rotation of the mass increased or diminished. From this there also follows directly the law of areas, or the law relative to the conservation of the moment of rotation whose application leads to the above theorem.

(2) The moment of rotation of a moving mass is diminished by the component of frictional resistance tangential to the direction of the circumference of the circle, namely, in the direction of the isobars.

(3) The effective force of a radial gradient can not again replace the loss of moment of rotation produced by frictional resistance, since according to Theorem (1), the effective force of a gradient can neither increase nor diminish the moment of rotation.

(4) In so far as a whirling system continually loses its moment of rotation by friction on the rough surface of the earth, but still continues its further rotation undiminished and therefore has a state of steady motion, it follows that a steady gain of moment of inertia coming from some other source compensates for the loss of moment of rotation due to friction. Now the system can receive no gain in moment of rotation, either from above out of the free interplanetary space or from below, and the forces due to the gradient are also excluded from consideration because they arise from the internal tension of the system, therefore we must recognize that the total work of friction which is done in the direction of the rotation, must be derived from the moment of rotation of the feeders themselves or the inflowing currents.

Applications under Group I.

(5) The large whirl of the temperate latitudes that gives rise to the westward trade, or is conditioned by it, and also attains a magnificent development in the

Southern Hemisphere suffers continual loss of rotary motion by reason of friction on the rough surface of the globe. The whole of this loss is entirely balanced by the moment of rotation of the feeders that flow inward as the upper westerly trades at high altitudes from the equator toward the polar regions. The work done by the meridional gradient force in this respect is zero if we examine it with mathematical exactness.

In so far as we must, in a special case, assume a velocity of zero for the wind component above the belt of high pressure in the direction of the circle of latitude, to that same extent must the whole whirl of the temperate and cold zones disappear; retarded by friction it must gradually come to rest or be broken up into regions of east and west winds.

(6) The living force or kinetic energy of the upper west trade or of its feeder is greater than the energy drawn from it by friction on the rough surface of the earth, because a part of the transferred energy is diffused by friction and mixture of masses in the overlying layer of air; that is to say, it is converted into heat.

On this point extensive investigations are at hand in the department of hydromechanics or the movement of water in rivers. For example, it is known that in deep streams scarcely one-third of the living force, or kinetic energy, communicated per second to it through the work done by gravity is in that same time destroyed by friction at the bottom of the stream; more than two-thirds of this increase in living force is dissipated in the water itself; that is to say, converted into heat (1).

In the second memoir (1) it is shown that the friction R at the ground is to be computed not from the work done per second by the force of gravity but by the quantity of motion communicated per second by the force of gravity (*i. e.*, the mass, m, multiplied by the increase, Δv, per second in velocity) or on the other hand, by the increase per second of the moving mass, Δm, multiplied by its velocity, v, so that we have the formula

$$R = v\Delta m.$$

Applying this formula to whirling motions we replace the quantity of motion by the moment of rotation and have

$$Rr = vr_1\Delta m$$

or, since r is variable because the friction affects every circular zone within the whirl, we have

$$\int dR.r = vr_1\Delta m.$$

In the application of this formula it is to be remembered that a steady condition of motion is assumed, that Δm indicates the mass added by the feeders per second, v is the component of the velocity of the feeder in the direction of the west wind, and R the friction in kilograms that the west wind experiences per unit element of the surface of the base of the whirl. This equation further assumes that the outflowing stream has no moment of rotation.

In so far as the outflow, *i. e.*, the return stream toward the hot zone, also appears in the form of a west wind or in our hemisphere a northwest wind, and in so far as there also occur in the cold zone local easterly winds for which we have to substitute the negative sign before the wind velocity we arrive at the following general theorem:

(7) In steady motion the difference between the moments of the momenta of the inflowing and outflowing streams is equal to the difference of the moments of friction produced by west and east winds within the system under consideration.

The following equation holds good:

$$\Delta m_1 v_1 r_1 - \Delta m_2 v_2 r_2 = \int dR_1 r - \int dR_2 r.$$

In this equation $\Delta m_1 v_1 r_1$ indicates the moment of the momentum of the feeder which brings the small mass Δm_1 per second within the whirl and adds it to this system. The quantity $\Delta m_2 v_2 r_2$ represents the moment of the momentum of the outflowing stream in so far as this has the same direction as the moment of the inflowing stream. If the outflow rotates with the earth as an east wind, while the inflow blows as a west wind, then the sign changes from minus to plus. The expression $\int dR_1$ gives the moment of friction of the west wind; the expression $\int dR_2 r$, gives the moment of friction for the east wind.

For systems the centers of whose whirls do not lie at the pole we substitute in the place of west or east wind the component of motion of the rotation to the right or left around the center of the whirl of the system.

(8) In so far as no moment of rotation is communicated to a system by the difference of the moments of the quantities of motion of the inflowing and outflowing currents, because the feeders show no whirl or the influence of the two currents annul each other, it follows that so far as a permanent steady condition is brought about the influence of the friction on their moments is nothing.

Therefore we have the following equation:

$$0 = \int dR_1 r - \int dR_2 r.$$

In this case the whole system is to be considered as divided into regions of opposite rotations whose moments of friction are equal to each other but have opposite signs. The whole atmosphere is subject to this condition as regards the east and west winds and so far as small cosmic influences, as yet unknown to us, do not introduce variations in the moment of momentum of the whole terrestrial atmosphere.

During this steady condition the moment of friction of the east winds for the whole earth is equal to the moment of friction of the west winds. On this point Ferrel (2) says:

"It is evident, however, that the east and west motions of the atmosphere at the earth's surface must be such that the sum of the resistances of each part of the earth's surface multiplied into its distance from the axis of motion must equal 0, else the velocity of the earth's rotation * * *."

(9) The location of the belt of high pressure that separates the region of east and west trade winds, according to theorem (8) is dependent to a very great extent on the distribution of land and water. If in the neighborhood of the pole there occur an extended continent, where therefore the earth's surface is rough, then the region of high pressure moves nearer the poles. Asia presents an example of this shifting.

If a rough surface occurred only in the neighborhood of the pole, while the rest of the earth's surface is quite smooth, so that frictional resistances were excluded from consideration in lower latitudes, then in this special case the region of east winds would extend from the equator to the neighborhood of the pole and cover also the border of the rough polar surface. At the pole itself and above

the rough land surface there would form a small cyclone of west wind. Almost the whole mass of the atmosphere would flow to the pole.

The oft-repeated attempt to compute the location of the zone of high pressure between the east and west trades without knowing the effect of friction is a labor that has no prospect of success. It is not to be encouraged, has led to very deceptive conclusions, and quite confused such readers of this class of memoirs as have not yet deeply studied the nature of the problem. The works of Werner von Siemens, although they should be thankfully accepted as stimuli, have unfortunately operated in this injurious manner. Notwithstanding the imperfect presentations and numerous erroneous conclusions contained in his memoirs, they still have permanent value on account of many correct fundamental ideas.

(10) Were the whole surface of the earth in general perfectly smooth, nevertheless a narrow zone of rough land area extending around the earth in but one hemisphere or even one single island existing therein, would suffice to determine the distribution of the regions of cyclonic and anticyclonic atmospheric motions over the whole surface of the earth.

(11) The theorems here deduced for the general circulation of the atmosphere also hold good, without great changes, for all smaller cyclones and anticyclones.

(12) If the equatorial zone were rough, but the remaining surface of the earth perfectly smooth, then almost the whole mass of the atmosphere would draw toward the equator, the pole being left almost wholly free from air. The belt of high pressure would almost coincide with and be narrower than the zone of rough land. The form of the atmosphere would approach that of Saturn's ring.

G. THE FORMATION OF THE GRADIENTS DEPENDENT ON INERTIA.

AUXILIARY THEOREMS, GROUP II.

(13) Air that moves freely in an inertia curve deflects neither to the right nor to the left from its orbit and therefore produces no pressure gradient perpendicular to the direction of its motion.

(14) Air currents that are forced to deviate to the right from their inertia paths produce higher pressure on the left hand or a pressure gradient directed toward the right perpendicular to the inertia path; conversely for deflection to the left the pressure gradient is directed to the left.

Applications under Group II.

(15) The inertia path shows in the Northern Hemisphere a deviation to the right whose value per second in $2w \sin \phi$, so that in $12 \frac{1}{\sin \phi}$ hours a curve somewhat like a circle will be described.

The following equation holds good,

$$2r\pi = v \times 12 \times 3600 \frac{1}{\sin \phi}$$

in which r indicates the radius of curvature of the curve of inertia, and v the wind velocity [i. e., relative to the earth's surface. EDITOR.]

$$r = \frac{v}{\sin \phi} \cdot \frac{12 \times 3600}{2 \times 3.14}$$

$$r = \frac{6880}{\sin \phi} \cdot v$$

For $\phi = 50°$ and $\sin \phi = 0.766$ we have $r = 8860v$, whence are derived the values,

when $v = 1$ meter, $r = 8.86$ kilometers.
when $v = 10$ meters, $r = 88.60$ kilometers.
when $v = 50$ meters, $r = 443.0$ kilometers.

When a wind of 1 meter per second velocity is forced to describe an anticyclonal path whose radius of curvature is smaller than 8.86 kilometers—or when a 50-meter wind is forced to describe a path whose radius is less than 443 kilometers there occurs the remarkable fact that in the center of the anticyclone a diminution of pressure is established. In this case the anticyclone becomes a barometric depression.

Local whirls, waterspouts, and many tornadoes offer examples of this sort of depressions—in which the rotation of the air is occasionally anticyclonal.

It is also to be remarked that in consequence of deviations of currents from the inertia path, all gradients at any altitude whatever possess full activity upward and downward. On the other hand, a storm occurring at any altitude in general and also at the bottom of the atmosphere will produce no gradient perpendicular to its movement when the air within it follows an inertia path undisturbed.

(16) The stronger the wind blows anticyclonally in a region of high atmospheric pressure, by so much the larger is the minimum radius of curvature of the isobars of that anticyclone.

(17) When the radius of curvature of the central isobars of an anticyclone with high pressure in the center, is zero it presupposes calm (in that region). Therefore near the central part of a high-pressure anticyclone calms prevail, for when calm does not prevail in the center of the anticyclone there arises there a low-pressure anticyclone, i. e., a depression with anticyclonal movement.

H. ON CONTRACTION AND DIVERGENCE OF WIND CURRENTS.

AUXILIARY THEOREMS, GROUP III.

(18) A current of air that suddenly passes from a region of strong gradients into a region of feeble gradients describes approximately an inertia-path in this passage. At the same time the gusts of wind previously parallel begin to describe convergent paths, so that in the midst of the current there is an accumulation of air and an increase of pressure as expressed by a zone of higher pressure that stretches along the axis of this stream. Furthermore, in the inner portion of the anticyclonal whirl there arises a diminution of pressure, a depression of the kind described in paragraphs (14) and (15).

(19) In so far as by the passage into regions of other gradients, the resulting deviations of the wind paths occur simultaneously, i. e., equally early, there arise contractions with the phenomena described in paragraph (18). But in so far as for a deviation toward the left, the left-hand jet is first deviated and the jets on the right hand of it, parallel to it deviate subsequently, there arise divergent rays that produce a groove of low pressure along their axes.

Applications under Group III.

(20) On the front of a depression advancing from west to east there blows a strong south wind. By the progress of the depression eastward the gradient changes (at any point) with the passage of the depression; in the Northern Hemisphere the gradient on the right-hand front of the depression turns toward the right hand. Near the center

of the depression this turn takes place with a greater velocity than corresponds to the expression $2w \sin \phi$. Consequently the wind that previously blew from the south completes a turn to the right that is completed quicker than corresponds to the inertia-path. In this act there occurs the contraction phenomena described in section (18). The change of barometric pressure clearly shows the advance of the zone of pressure that must form at the point and the movement change in direction of the wind. Here occurs the well-known sudden rise of pressure of from ½ to 2 millimeters which is observed at every sudden change in direction of the wind in the direction of the curve of inertia and especially during thunderstorms. The air thus temporarily compressed below expands upward and favors the formation of sudden heavy rainfalls of short duration.

In this special case the phenomena here described are intensified by the relations mentioned in section (19), especially because the deviation to the right here of the left-hand streamers first and the right-hand last increases the convergence of the jets.

The meaning of the convergence and divergence of the upper and lower winds is reported on in the work: "Beziehungen, etc., [Relation between the upper and lower winds of a depression and the cloud forms resulting therefrom]" in Annalen der Hydrographie und maritimen Meteorologie, Jhrg. 1882, Heft iv, Berlin.

Similarly it has been shown that the behavior of the electric and magnetic attractive and repulsive forces is to be referred back to the results that arise when wave-like rays possess diverging or converging directions. By the study of these processes there opens up to us a clear view of the dynamic properties of the etherial forces known as electricity and magnetism. Thus that elastic strain that Farraday and Maxwell recognized by its effects as a process in space, but which had not yet been analyzed into its details, is now set forth before us.

The final results agree exactly with the results deduced by Maxwell—these deductions are given by me in my book (3) on electricity and magnetism.

Theoretical physics has hitherto given but little attention to the phenomena of suction and obstruction in fluid motions but these processes are of the highest importance in studying the relations existing between dynamic and static pressure, and that, too, as much so in reference to the movements of material systems as in movements of the ether itself.

Of course, it is known to me that other theories have also been advanced endeavoring to explain the temporary rise of the pressure during thunderstorms and on the occasion of sudden changes in the direction of the wind, but I believe that I can refute all such theories so far as they are as yet known to me.

(21) The upper winds flowing poleward at great altitudes from the lower latitudes, are in their progress subject to the deflecting force of the earth's rotation, which at first at the equator has the value of zero. These upper winds move under conditions similar to those for the south wind described in section (20), only in this case it is the poleward progress of the current in the higher latitudes that causes a bend in the inertia path, thereby producing a convergence of the currents. The accumulation thus produced in consequence of the convergence of the inertia-curves develops upward and, in opposition to the conditions described in section (20), now causes a compensating current directed downwards, corresponding to the rainless weather of the dry zone.

These processes are described by me in the memoir "Ueber den Kreislauf atmosphärischer Luft zwischen niederen und höheren Breiten [The interchange of atmospheric air between lower and higher latitudes.]" (Aus dem Archiv der Deutschen Seewarte, Vol. X, 1887, No. 3) and especially on pages 14 and 15 of that memoir are these submitted to a special computation. A short extract from this memoir is also given by Frank Waldo, in his work "Modern Meteorology," on pages 311–315 with a plate.

E. Herrmann's notice of my analysis (Met. Ztschr., April, 1893, 10. Jhrg., p. 132) is, unfortunately, misleading. He substitutes the convergence of the meridians for the convergence of the inertia-curves. The former acts in the same direction but much more feebly than the latter. He has not appreciated the finer points of my investigation.

I. PROCESSES THAT DO NOT CORRESPOND TO THE STEADY CONDITION.

AUXILIARY THEOREMS, GROUP IV.

(22) In so far as an outflow above and an inflow below is set up within a previously quiet region by means of a warming at the central region, C, there is formed a cyclone below and an anticyclone above, but the latter immediately forms an eye at the center above C, where cyclonal motion has been established. Therefore the upper anticyclone forms only a ring in whose interior a cyclone occurs, which latter expands in proportion as air rises from below to the top, and is endowed with cyclonal motion and imparts cyclonal rotation to the upper layer. In this connection the gradients (of pressure) do not work, they are directed only toward the moment of rotation. (See theorem No. 1.) The upper ring of air endowed with anticyclonal motion, widens and wherever it passes over a region on the earth it temporarily influences the weather and the wind.

(23) When a depression coming from the ocean turns toward a continent, the whirl will in its lower part be enfeebled by the roughness of the land. At once there develops within the depression an active inflowing and ascending current of air, so that heavy precipitation falls. Furthermore, cold air is often carried upward in this case, whereby the depression receives a further enfeeblement or even complete dissolution.

(24) In the development of a region of high pressure the air must flow inward anticyclonally, by reason of which the anticyclone should show a longer duration than the cyclone. The anticyclonic feeder can flow into the anticyclone either above, from a depression with ascending air currents, or below from a depression with descending air currents. In the latter case, this process of the development of the anticyclone is connected with precipitation.

(25) In so far as the column of air cools at the center C, the upper air flows cyclonally from all sides toward the center C. On the other hand, a region of high pressure develops below in proportion as the upper air flows inward; furthermore, there develops below an anticyclonal outflowing movement of the air. The upper cyclone that has developed above the anticyclone, extends downward to the lower strata in proportion as the lower anticyclonal-moving air flows away and is replaced by air in cyclonal motion. The area of high pressure in the anticyclone flattens out and local depressions form where

the air descends most decidedly from the upper layer. The anticyclone is now arrived at the process of dissolution.

K. CONCLUSION.

(26) The literature of the past 10 years [1883–1892] contains numerous expressions of opinion that are opposed to the laws of atmospheric motion; we may infer that the readers have thereby been led into error.

Too seldom do the mathematicians describe the process that they propose to submit to calculation. The whole presentation of the subject under computation may be erroneous or at least imperfect. The reader is not always able to determine to what extent the results of the computation have practical applications. For instance, Ferrel has not especially, in fact scarcely at all, considered the fact that the upper and lower strata of the atmosphere accomplish an equilibration of their moments of inertia by reason of a continuous steady mixture of their masses steadily as well as periodically renewed.

Again, the result that the belts of high pressure that inclose the hot zones ought to occur in the neighborhood of latitude 30° arises from an arbitrary assumption as to the magnitude of the total moment of rotation of the whole atmosphere, that is made even before the beginning of his analysis.

It is to be considered that the transportation of a kilo gram of air from the region of the pole to that of the equator or conversely, assuming the velocity of the wind to be zero at the beginning and the end of the transfer, expends an amount of work or absorbs an amount of work equal to about 20,000 kilogram-meters; so that the air coming from the equator transfers its kinetic energy or its moment of rotation to the air flowing in the opposite direction, either by direct processes of mixture of masses, or by means of friction on the rough ground in the cyclones and anticyclones, and therefore by the tension from west to east arising from the reaction between the ground and the air. In Ferrel's theories the very important processes of mixture of masses and the interchange of moments of rotation are scarcely mentioned, and therefore Ferrel's theoretical deductions give such large wind velocities and such slight values of the atmospheric pressure at the poles.

The solution of problems in dynamic meteorology are still always merely partial solutions that are only applicable between definite limits and under special assumptions. Therefore the numerical values thus obtained should not be considered, either by the mathematicians or the reviewers, as "refined gold" since thereby the theory would be brought into discredit.

Empiricists are inclined to reject not only the recognized imperfect numerical results of any theory, but also the good ideas on which these are based.

Hitherto theory has dealt too little with numerical results; we have been satisfied with the deduction of formulæ and therefore have not learned the useful applications of theory so quickly as would have been attained by more frequent execution of numerical calculations. In general, meteorologists themselves do too little observing. They know only so much of the weather processes as the observers communicate and important details remain unrecognized. No clear connected view of the weather processes can be obtained in this way.

The details of the theory of vortex motions, so far as they have been thoroughly developed in mechanics for the construction of turbines and centrifugal pumps and blowers, are too little known to meteorologists. At the present time we frequently find in meteorology efforts to establish new theoretical relations that have already been expounded with perfect clearness in practical mechanics.

Again, the theory of the processes of suction and obstruction ("Stau- und Sauge-Vorgänge") are not sufficiently studied by meteorologists and physicists, nor the conditions, circumstances, and extent to which work is performed or prevented in the atmosphere.

From the above exposition it follows that the mechanics of cyclones and anticyclones stands in close dependence on the work of the late eminent mathematician, William Ferrel; but can now be best furthered by simultaneous thorough consideration of the processes in space (viz, geographic) and by personal observation of all the details of the weather phenomena as found by studying the important synoptic weather charts and telegraphic weather reports.

Personal studies of this kind are, however, prevented by want of time and the modern system of the subdivision of work. Especially does the latter make it difficult for a single person to attain a general oversight of the whole subject. A subdivision of work is indeed demanded in the interests of a successful service in every meteorological institution; however, it should not be pushed so far that a meteorologist is prevented from the execution of personal observations or is robbed of the time needed to enable him to become well grounded in theoretical researches.

At the present time the development of the science of meteorology is directed too strenuously toward the subdivision of labor. We imagine that by the increase of ordinary observational data we may gain a general oversight of the subject. In reality, the labor applied to ordinary statistics and the conduct of the general service is thereby so greatly increased that there is no time or thought left for the practice of independent higher studies. One's interest is too much diverted from the consideration of the weather phenomena as a whole, and also from important details, such as the observation of the clouds and the method of formation of falling rain.

These defects, due to the unavoidable necessity of the subdivision of labor, are only to be overcome by the freest personal interchange of views, in order that the labors of many assistants may be made most profitable and productive by practically skillful, well-di ected, and liberal-minded administration.

REFERENCES.

(1) On this point compare the following:
"Ueber Wasserbewegung im Strom und Gestaltung der Flussohle," Ztschr. d. Archit. u. Ingenieurver., Hannover, Jhrg. 1890, p. 455–467.
"Ueber den Begriff Reibung und Bewegungsgrösse (Kraft) bei fliessenden, schwingenden und gleitenden Massen," Verhdlg. d. Vereins z. Beförd. d. Gewerbefleisses, Berlin, Jhrg. 1890, p. 231–252.
(2) **Ferrel, Wm.** Meteorological researches for the use of the Coast Pilot. Part 1: On the Mechanics and general motions of the atmosphere. Washington. 1877. p. 42, par. 38. f°. (U. S. Coast survey. [Publication])
Sprung, A. Lehrbuch der Meteorologie. Hamburg, 1885. p. 202.
(3) **Möller, Max.** Das räumliche Wirken und Wesen der Elektrizität und des Magnetismus. Mauz & Lange, Hannover, 1892. illus.

THE HALOS OF NOVEMBER 1–2, 1913.

[Translated from Annuaire, Soc. météorologique de France, mai, 1914.]

Mr. Louis Besson offered a communication [May 5, 1914] on the oblique arcs of the anthelion. This phenomenon, one of the rarest connected with unusual halos, has been seen two days in succession in the United States, November 1 and 2, 1913.

The observations made on that occasion will soon be published in the United States Monthly Weather Review of the Weather Bureau. Unfortunately, they do not sensibly increase our knowledge of the oblique arcs of the anthelion, whose mode of production remains obscure. By examining closely what has been stated by Bravais, Mr. Besson has determined that he can account for only the short arcs, deviating a little from the anthelion upward, but not at all for those which extend as far as the region of the sun. It is very desirable that at their next appearance the oblique arcs of the anthelion be observed with more precision and more detail than previously. A photograph, especially in the case of short arcs, will be the most instructive document. If the arcs are long, it will be proper to give attention to the following points:

Are these true arcs of the circle, or, in other words, is their curve uniform and, in this case, what is their radius of curvature?

What is the angle between them at their point of crossing over the anthelion?

At what distance from the zenith do they pass?

At what point of the sky do they recross?

Is this exactly on the sun?

It is indispensable to note the exact time when the observation was made, for the character of the phenomena must vary with the height of the sun.

Mr. Lemoine thinks that it would be advantageous, in the study of halos, not to confine ourselves to observation, but to consider also methods of experimentation. With the present resources of our laboratories we can reasonably produce artificially various crystalline forms of ice and study their optical properties.

Mr. Besson says that he shares entirely the opinion of Mr. Lemoine, and that he has never neglected an opportunity to point out to physicists and to laboratory crystalographers the experimental study of the crystallization of ice as an interesting and certainly profitable study, but up to the present time he has not succeeded in interesting any one who possessed the necessary equipment.

On the other hand, he took occasion to remark that, in the study of halos, observation and experiment each has its own domain—the first alone can make known to us the natural phenomena to be explained; the second is for the purpose of teaching us the various possible forms of ice crystals and showing us which can best account for the optical appearances.

Mr. Goutereau recalls that Mr. Besson, in his researches on halos, had recourse to experimentation to determine the orientation that ice crystals take in falling.

HALOS IN FEBRUARY, 1914.

The following report by Daingerfield of the halo seen on February 6, 1914, at Pueblo, Colo., and again the reports by Flora, Holcomb, and Judy of the halo seen on February 24, 1914, in Kansas, are reprinted from the respective Monthly Section Summaries by request of Prof. C. F. Talman, as referring to rarer forms of halos and of interest to students of halo phenomena.—[C. A.]

REMARKABLE HALO AT PUEBLO, COLO., FEBRUARY 6, 1914.

Mr. L. H. Daingerfield, Local Forecaster, Pueblo, Colo., sends a report and drawings of a remarkable solar halo observed at that place between sunrise and 9 or 9:30 a. m., February 6, 1914, by Mr. W. F. Doertenbach, Mr. J. K. Sweeny, and himself. The phenomenon included a complete and brilliantly colored halo of 22° radius around the sun, part of a fainter halo of 46° radius, a complete parhelic circle, a brilliant circumzenithal arc, parhelia of 22° and 46°, and a sun-pillar forming a cross with the parhelic circle. Fragments of another heliocentric halo, described as about 66° from the sun, with paranthelia at their point of intersection with the parhelic circle, are also mentioned in the report. As these arcs do not agree in position with any known form of halo and as the report states that "the color may have been altogether white," it seems possible that these were fragments of the halo of Hevelius (the 90° halo).

One of the drawings (none of which are reproduced) sent by Mr. Daingerfield shows the circumzenithal arc forming a complete circle, also an arc of a halo of about 22° radius, prismatically colored, surrounding the point opposite the sun in azimuth, as well as certain other features that do not correspond with any forms of halo heretofore recorded. It also shows four paranthelia, two at the point of intersection of the small halo opposite the sun with the parhelic circle, and two on the parhelic circle about 60° from the antisolar point. This drawing appears to be a composite of the observations of several persons.—[C. F. T.]

UNUSUAL SOLAR HALOS SEEN IN KANSAS ON FEBRUARY 24, 1914.

Solar halos of unusual appearance were observed in eastern, northern, and central Kansas on February 24, 1914, from 9 a. m. to 10 a. m., and sun dogs (parhelia) of considerably more than usual brilliancy were seen from

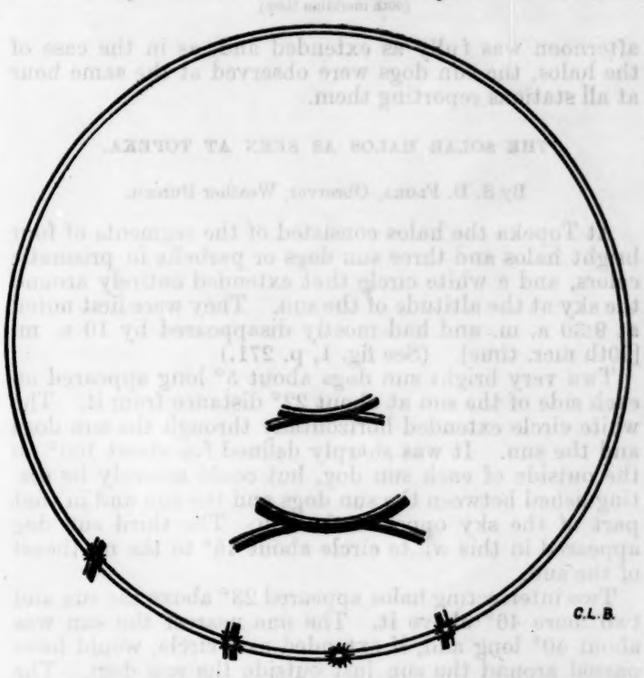


FIG. 1.—Solar halos seen at Topeka, Kans., February 24, 1914, between 9:30 and 10 a. m. (90th meridian time).

4 to 5:30 p. m. of the same day over the northern and central portions of the State.

From the meager descriptions received it is believed that halos reported at Hoxie, Kans., Beloit, Wis., Minneapolis, Minn., and Council Grove, Kans., were similar in

a general way to those at Topeka, Iola, and Garnett, Kans., descriptions of which appear in this article. Over this area, extending more than 250 miles west and 75 miles south of Topeka, the halos were observed at practically the same hour.

The territory covered by the stations reporting either two or three brilliant sun dogs (or parhelia) in the late

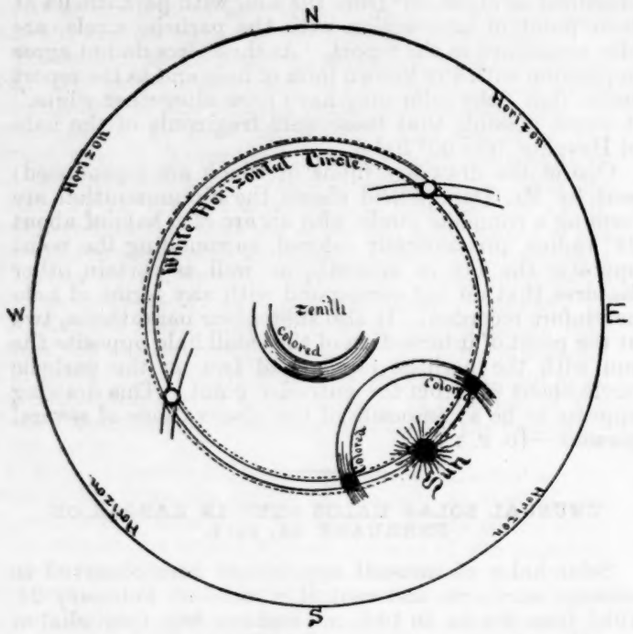


FIG. 2.—Solar halos seen at Iola, Kans., February 24, 1914, between 8:30 and 11:25 a. m. (90th meridian time).

afternoon was fully as extended and, as in the case of the halos, the sun dogs were observed at the same hour at all stations reporting them.

THE SOLAR HALOS AS SEEN AT TOPEKA.

By S. D. FLORA, Observer, Weather Bureau.

At Topeka the halos consisted of the segments of four bright halos and three sun dogs or parhelia in prismatic colors, and a white circle that extended entirely around the sky at the altitude of the sun. They were first noted at 9:30 a. m. and had mostly disappeared by 10 a. m. [90th mer. time]. (See fig. 1, p. 271.)

Two very bright sun dogs about 5° long appeared on each side of the sun at about 22° distance from it. The white circle extended horizontally through the sun dogs and the sun. It was sharply defined for about 100° on the outside of each sun dog, but could scarcely be distinguished between the sun dogs and the sun and in that part of the sky opposite the sun. The third sun dog appeared in this white circle about 46° to the northeast of the sun.

Two intersecting halos appeared 23° above the sun and two more 46° above it. The one nearest the sun was about 40° long and, if extended as a circle, would have passed around the sun just outside the sun dogs. The second prismatic halo was turned convexly to the sun and overlapped the first just above the sun. It was only 30° long, but was the brighter of the two, and this made the longer halo, the one turned with its concave side to the sun, have at first appearance the shape of the bow generally shown in the pictures of Cupid. The segment of the halo turned convexly to the sun seemed to indicate that this halo, if complete, would have been elliptical.

The two halos 46° above the sun were arranged and colored similarly to the ones at 23° distance, but each was only about half as long.

In each halo that the spectrum colors appeared the reddish tints were on the side nearest the sun. By 10:00 a. m. only the sun dogs were visible and these disappeared by 11:00 a. m.

The sky during this time was partly covered with a veil of cirro-stratus clouds so thin that they gave it a milky rather than a cloudy appearance except just a few places where the clouds were plainly apparent. Most of the halo formation appeared where the clouds were thin.

THE SOLAR HALOS AS SEEN AT IOLA.

By H. K. HOLCOMB, Observer, Weather Bureau.

A complete circle of white light, two incomplete solar halos, and four mock suns were observed from 9:15 a. m. to 11:25 a. m. [90th mer. time], February 24, 1914, at this station. (See fig. 2.)

Portions of the above phenomenon were observed as early as 8:30 a. m. and gradually disappeared between 10:30 and 11:25 a. m. The large, complete circle of white light, parallel to the horizon, at the altitude of the sun, was the most conspicuous part of the phenomenon. There

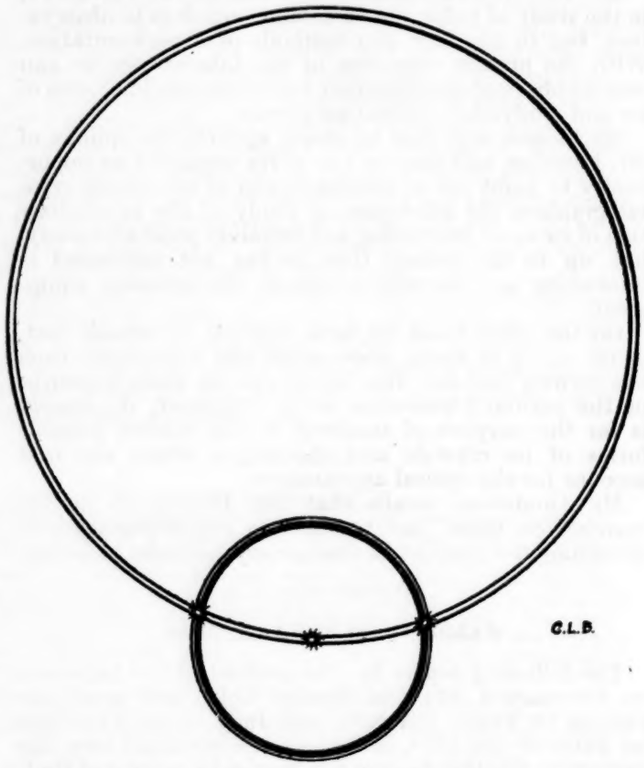


FIG. 3.—Solar halo seen at Garnett, Kans., February 24, 1914, at 9:30 a. m. (90th meridian time).

was an incomplete solar halo of 22° radius, and another very faint solar halo of 90° radius. Where these halos crossed the ring of white light mock suns were produced. The inner halo and the two mock suns were well defined and colored with red on the inner side, blending with orange, yellow, green, blue, and vanishing with purple on the outer side. Nearer the zenith another similarly col-

ored arc of a circle convex to the sun was observed. Where the faint halo of 90° radius intersected the ring of white light, the arcs and the outer two mock suns were of bright white light.

During this time the sky was partly covered with a thin veil of cirrus and cirro-stratus clouds from the north.

THE SOLAR HALOS AS SEEN AT GARNETT, KANS.

By D. D. JUDY, Cooperative Observer.

On February 24, 1914, beginning with 9:30 a. m. [90th meridian time] two solar halos were seen in the sky. As shown by figure 3 there was a small one around the sun colored like the rainbow, that lasted but a short time and a large white circle extending from the sun northward, with 2 sun dogs, one on each side of the sun.

[Features of special interest in the observations above reported are:

(1) In the phenomenon seen at Topeka, the overlapping of the 22° halo and its upper tangent arc. Similar observations have sometimes been reported in connection with the 46° halo, or, properly speaking, the "upper bitangent arc" of this halo, seen overlapping the circumzenithal arc, but this appearance in connection with the 22° halo seems to be new to science.

(2) In the Iola observation the arcs of the 90° halo, with paranthelia. This is the rare "halo of Hevelius," which was also reported in connection with the remarkable halos of November 1–2, 1913.—[C. F. T.]

52003—14——2

SECTION II.—GENERAL METEOROLOGY.

LAND AND SEA BREEZES.[1]

[Communicated to the International Meteorological Congress at Chicago, August, 1893.]

By Prof. ROBERT DEC. WARD.

[Dated, Harvard University, July 1, 1893.]

HISTORY OF THE THEORY.

It is the purpose of this paper to present a brief review of the most important publications on land and sea breezes, in order that it may be seen just where we stand in our knowledge of the phenomena and mechanism of these winds. The aim of the essay is, therefore, not to present any new facts, but simply to summarize those facts which have been already brought out by preceding writers. In compiling this review the present writer has merely condensed what is contained in the report on the sea breeze published by Harvard College Observatory (1). That report contains an historical account of the theory of land and sea breezes, as well as the results derived from the study of the sea breeze undertaken by the New England Meteorological Society during the summer of 1887.

One of the earliest as well as one of the best descriptions of land and sea breezes is given by the old navigator Dampier (2). The account is so good that it deserves quotation at some length here.

> Sea breezes, he writes, generally speaking, are no other than the common trade wind of the coasts on which they blow, with this difference, that whereas all trade winds, whether they are those that I call the general trade winds at sea, or coasting trade winds * * * do blow as well by night as by day, with an equal briskness, except when tornadoes happen; so contrarily sea winds are only in the day and cease in the night; and as all trade winds blow constantly near to one point of the compass * * * on the contrary these sea winds do differ from them in this, that in the morning, when they first spring up, they blow commonly as the trade winds on the coast do, at or near the same point of compass; but about mid-day they fly off about two, three, or four points farther from the land, and so blow almost right in on the coast, especially in fair weather, for then the sea breezes are truest. * * * These sea breezes do commonly rise in the morning about nine o'clock, sometimes sooner, sometimes later; they first approach the shore, so gently, as if they were afraid to come near it, and ofttimes they make some faint breathings and, as if not willing to offend, they make a halt, and seem ready to retire. * * * It comes in a fine, small, black curle upon the water, when as all the sea between it and the shore not yet reach'd by it is as smooth and even as glass in comparison; in half an hour's time after it has reached the shore it fans pretty briskly, and so increaseth gradually till twelve a-clock, then it is commonly strongest, and lasts so till two or three a very brisk gale; about twelve at noon it also veers off to sea two or three points, or more, in very fair weather. After three a-clock it begins to die away again, and gradually withdraws its force till all is spent, and about five a-clock, sooner or later, according as the weather is, it is lull'd asleep and comes no more till the next morning. * * *
>
> Land breezes * * * are quite contrary to the sea-breezes; for those blow right from the shore, but the sea breeze right in upon the shore; and as sea breezes do blow in the day and rest in the night; so on the contrary, these do blow in the night and rest in the day, and so they do alternately succeed each other. For when the sea breezes have performed their offices of the day, by breathing on their respective coasts, they in the evening do either withdraw from the coast, or lie down to rest; then the land winds, whose office is to breathe in the night, moved by the same order of divine impulse, do rouse out of their private recesses and gently fan the air till the next morning; and then their task ends and they leave the stage. * * *
>
> The sea breezes indeed are very comfortable and refreshing; for the hottest time in all the day is about 9, 10, or 11 o'clock in the morning, in the interval between both breezes; for then it is commonly calm, and then people pant for breath, especially if it is late before the sea breeze comes, but afterwards the sea breeze allays the heat.

The occurrence of the land and sea breezes, which has been observed and described by very many writers, although by none more clearly than by Dampier, was early rightly explained as being due to the diurnal warming and cooling of land more than water. A common form of statement of this theory, which we may call the simple convectional theory, is found in Buchan's (3) Text Book of Meteorology (1871), in which the author says that the land is

> heated to a much greater degree than the sea during the day, by which the air resting on it being also heated, ascends, and the cooler air of the sea breeze flows in to supply its place. But during the night the temperature of the land and the air above it falls below that of the sea, and the air thus becoming heavier and denser flows over the sea as a land breeze.

This simple convectional theory has been almost universally accepted by those who have written on this subject. Among the more prominent authors who have adopted this theory may be mentioned the following:

Capper, 1801.	Fitzroy, 1863.
Maury, 1856.	Marié-Davy, 1879.
Mühry, 1860.	Geikie, 1879.
Herschel, 1861.	Loomis, 1885.
Dove, 1862.	Mohn, 1887.

This theory requires that the sea breeze shall begin near the shore and gradually extend backwards out to sea, for it is the air near the shore which will first flow in to take the place of the warmed and ascending air over the land. Maury in his "Physical Geography of the Sea," describes this action as follows:

> About 10 in the morning the heat of the sun has played upon the land with sufficient intensity to raise its temperature above that of the water. A portion of this heat being imparted to the superincumbent air, causes it to rise when the air, first from the beach, then from the sea, to a distance of several miles, begins to blow in.

Mühry (4) also says: "The sea breeze begins in the neighborhood of the coast, and gradually prolongs itself backwards, because its motive is 'aspiration' in the region in front of it." The sea breeze, however, does not begin at the shore, but first appears some miles out at sea, gradually working its way towards the shore. This fact was clearly brought out in Dampier's account, already quoted, his statement being that the breeze comes as "a fine, small black curle upon the water, when as all the sea between it and shore not yet reached by it is as smooth and even as glass in comparison." Jansen, quoted by Maury, says that:

> Far out upon the sea arises and disappears alternately a darker tint upon the otherwise shining sea-carpet; finally, that tint remains and approaches; that is the long-wished-for sea breeze; yet it is sometimes one, yes, even two hours before that darker tint is permanent, before the sea breeze has regularly set in. * * * We welcome the first breath from the sea; it is cooling, but it soon ceases; presently it is succeeded by other grateful puffs of air, which continue longer; presently they settle down into the regular sea breeze with its cool and refreshing breath.

This off-shore beginning of the sea breeze has also been carefully described by several other observers, including

[1] The present paper was prepared for publication in 1901, but has been delayed for the reasons stated in the REVIEW for February, 1914, 42: 93.

some of those who took observations for the New England Meteorological Society in 1887, and there is no reason to doubt that this feature is a general characteristic of this wind, and as such it should be accounted for by the theory. As the simple convectional theory, above outlined, stands, it gives no explanation of this fact.

This failure of the generally accepted theory to explain the off-shore beginning of the land breeze led Laughton (5) to put forward a different theory. He does not consider the differences of temperature between the land and sea sufficient to produce land and sea breezes, and finding that the sea breeze is most distinct on coasts with a mountain range in the background, gives the following explanation. The sea breeze is not due to a decrease of pressure in front, over the land, but to an increase of pressure behind, over the sea, this increase of pressure being derived from the water vapor formed over the sea, aided, in the case of mountainous coasts, by the withdrawal of water in the rainfall there induced. The land breeze is ascribed to the accumulation aloft of the air brought in by the sea breeze, which descends in the evening and slides back towards the sea again. Admitting that vapor pressure may aid in producing the sea breeze, and that the presence of mountains near the coasts may also be of help in confirming the circulation, still it is impossible to believe that the air brought in by the sea breeze can remain stationary aloft near the coast until the cessation of the on-shore wind allows this mass of air to move seaward again.

Another view, which has been adopted by Hann and Scott, is that of Blanford, whose recent death [Jan. 23, 1893] has removed from the ranks of meteorologists one of the most active and valuable of workers. Blanford has shown that the air over the land, heated by contact with the warm ground, is expanded much more than that over the sea, where the heat is largely used in evaporating the water. The result is that the isobaric surfaces are expanded over the land, and given a slope seaward, the steeper slope being aloft. Down this slope the upper strata of air over the land slide seaward, and thus an increment of pressure is produced at some distance off-shore. This results in an inflow of air from over the sea towards the land, where there is rarer atmosphere and lower pressure, and in this way the off-shore beginning of the sea breeze is explained. During the night the opposite conditions prevail, and the land breeze results.

Köppen (6) has objected to Blanford's theory on the ground that the removal of the upper air from over the land in the morning will relieve the pressure over the land by just as much as the pressure over the sea is increased, and that therefore the air nearest the shore will flow in first, as in the case of the draught of a fire. He therefore suggests as the cause of the off-shore beginning of the sea breeze that the air near the land is held back by friction with the ground, thus forming a cushion against which the sea breeze strikes and by which it is kept out from the shore until the differences of pressure have become great enough to overcome the opposition. Although this friction may be important in the case of rugged and mountainous coasts, it hardly seems possible that it can be efficacious on low and sandy shores.

The difficulty of giving an adequate explanation of the offshore beginnings of the sea breeze has been successfully met by Seemann (7), a captain in the German merchant service. After careful observation of the phenomena of sea breeze action in different harbors to which his occupation as shipmaster has taken him, and especially in the harbor of Valparaiso, where the advance of the breeze toward the shore is very clearly marked, Seemann puts forward a new view, which is as follows: As the land is warmed in the morning more than the sea, and the air over the land more than that over the sea, there comes to be a broad mass of expanding air over the land, pushing not only upward against the cooler overlying air, but outward as well. It is this lateral expansion of the warmed air over the land which prevents the early and immediate entrance of the sea breeze, and which often produces an increase of the off-shore land breeze in the early morning hours. This latter point is well shown at Rio Janeiro, where the land breeze is strongest about 8 a. m. and is of great service in helping vessels to leave that port, and also at many other places. The sea breeze is kept out because the warming air over the land is able by its increasing expansive force, to balance the increasing weight of the air over the sea. As long as the temperature over the land rises rapidly the expansive force of the warming air is able to keep out the sea breeze. But at 11 a. m., or thereabouts, when the increase of temperature over the land is no longer so rapid and when the increase of pressure over the sea has become greater, the sea breeze can push forward nearer the shore. Finally, when there is no longer an increase of temperature over the land, there is no more opposition, and the sea breeze can blow all the way to the shore and beyond it for some miles inland.[1]

A series of tables, given by Blanford, showing the changes of pressure over the land at Calcutta and over the sea at the Sand Heads Lightship, 60 miles offshore, give a striking confirmation of Seemann's theory. From these tables it is seen that between 1 and 2 a. m. the pressure over the land becomes greater than that over the sea, and then the land breeze begins. This difference in pressure increases till 4 a. m., and then slowly decreases till 6 a. m. A rise in pressure is then noted, owing to the expansion of the air over the land by warming, the maximum being reached at 9 a. m. After this the difference in pressure becomes less as the temperature rises more slowly and the upper layers of air flow off seaward. At 1 p. m. the conditions change and the sea breeze comes in, reaching its greatest velocity between 3 and 6 p. m., when the differences in pressure are greatest. By 8 p. m. the difference in pressure is small; by 9 p. m it is almost gone, and at 1 a. m. the conditions are reversed again.

MAIN FEATURES OF LAND AND SEA BREEZES.

Having thus briefly reviewed the history of the theory of land and sea breezes, it remains for us to note some of the main features of these winds. These we shall take up under the headings: (1) Relations of land and sea breezes to general weather conditions; (2) Dimensions and physical features of the sea breeze; (3) Effects of the earth's rotation on the course of the breezes; (4) Combination of land and sea breezes with other winds; (5) Effect of land and sea breezes on the distribution of aqueous vapor. We must of necessity treat each of these headings very briefly.

Relations to general weather conditions.—In most of the accounts of land and sea breezes mention is made of the fact that they are best developed in fine summer weather,

[1] A more recent discussion of the circulation in the sea breeze, and its origin, is given by Sandström in Bull., Mt. Weather obsy., 1912, 5, p. 90-91.—EDITOR.

and of their absence on cloudy or stormy days. Dampier, with his keen observation, noted this in his account which we have quoted, for he speaks of the sea breeze as being "truest" in fair weather. The reason for this is obvious. On clear days, when the anticyclonic conditions and faint gradients generally prevail, the conditions for the diurnal warming and cooling necessary for the production of these winds are usually favorable, and there is little or no interference through the presence of strong cyclonic winds. In the torrid zone, where even conditions prevail throughout the year, these breezes are a persistent climatic feature. In the temperate zones they are characteristic seashore phenomena of fine summer weather, when the conditions are favorable.

Dimensions and physical features.—The most reliable observations on the vertical thickness or height of the sea breeze were made by C. T. Sherman at Coney Island, near New York, some few years ago by means of captive balloons. From 12 observations thus made the average height of the sea breeze was found to be 410 feet, and the base of the return current was noted at 525 feet. The average temperatures were found to be 77°.1 at the earth's surface; 75° at 100 feet above the surface and 74°.5 at 200 feet above the surface. Balloon ascents by Duruof and Tissandier at Calais, August 16, 1868, and by Eloy and Lhoste at Boulogne, June 6, 1883, furnish good evidence as to the lower on-shore breeze and the upper return current, but give no reliable measurements.

As regards the distance of penetration inland, and the rate at which the sea breeze advances, Blanford states that the breeze is sometimes felt at Calcutta, 68 miles from the sea. In New Jersey it has been noted at a distance of 40 miles from the shore, the time taken by the breeze in advancing over that distance being four or five hours. In New England the inland limit of the sea breeze is between 10 and 20 miles and the rate of advance at the shore is 10 to 15 miles an hour, but diminishes rapidly further inland. The breezes are usually of very moderate velocity, unless combined with other winds, the velocity of the land breeze being less than that of the sea breeze.

The effect of the on-shore breeze during the day is naturally to lower the temperature of the places reached by it, the result being that the maximum temperature of the day occurs in the middle of the morning instead of in the early afternoon. The sea breeze, with its cooling effects and its fresh sea smell, is one of the most delightful features of the climate of many seashore districts, adding much to the comfort as well as to the health. The breeze is often noted as causing the sky to darken a little toward the horizon as it approaches. This fact is in all probability due to the greater cleanness of the air from the sea, the luminosity of the sky depending as is well known, on the amount of dust or haze in it.

Effects of the earth's rotation.—The deflective effect of the earth's rotation, which tends to turn moving bodies to the right of a direct course in the Northern Hemisphere and to the left in the Southern, is well established in the case of the land and sea breezes. The veering in this hemisphere of these breezes has long been recognized. Capper in 1801, noted the fact that the on-shore wind seemed regularly to follow the course of the sun, passing around every point of the compass in 24 hours. Chambers, in his discussion of the hourly wind observations at Bombay (8), has brought out this point very clearly. The sea breeze when it is best developed, during the offshore winter monsoon, begins in the west and veers to the north. A similar example is found in H. A. Hazen's (9) "Report on Wind Velocities at the Lake Crib and at Chicago," in which it is seen that the mean hourly direction of the wind at Chicago during July, 1882, changed from almost due east at 1 p. m. through southeast to almost south at 10 p. m. In the investigation of the sea breeze in New England during the summer of 1887 this veering was also very distinctly recognized in several cases. The veering (in this hemisphere) is noted in the afternoon and at night, as the sea and land breezes are derived from a greater and greater distance from the shore.

Combination with other winds.—The combinations of the land and sea breezes with the other winds which may prevail during their occurrence, are many. On mountainous tropical islands the sea breeze combines with the diurnal valley wind blowing up the mountain sides to form clouds and often rain on the mountains. As soon as the land breeze begins the clouds disappear. Hann, in his "Klimatologie" (10), notes that where the sea breeze has the same direction as the prevailing wind it usually increases during the afternoon to a gale, while the land breeze is hardly noticeable. On coasts with offshore winds the land breeze is stronger, while the sea breeze frequently simply lessens the velocity of the prevailing wind. Koeppen (11) maintains that in cases where the prevailing winds are offshore the sea breeze either overcomes these winds entirely and is felt as a distinct wind from the sea, or else the trades continue uninterruptedly throughout the day. Other examples of the combination of land and sea breezes with prevailing winds are given by Maury, Loomis, Schmid, and others.

Effect on the distribution of aqueous vapor.—In his report on atmospheric circulation, based upon the results of the *Challenger* Expedition, Buchan points out that land and sea breezes have a marked disturbing effect on the diurnal distribution of aqueous vapor in the lower stratum of the atmosphere. Over the open sea, at some distance from land, the typical curve of humidity has its maximum and minimum at the times when the temperature of the sea surface and of the air lying over it has its maximum and minimum. Under the influence of the land breeze the minimum humidity is not reached till about 6 a. m., and there is further a secondary minimum of humidity for some hours between 10 a. m. and 4 p. m., during the time when the ascending current from the land is strongest and the sea breeze is also strongest. This diminution in the amount of aqueous vapor near the land Buchan believes to be due to an intermixture with the sea breeze, of descending currents of air coming down to take the place of the air which has been removed by the ascending currents over the land. In this way the dryness of the air of the sea breeze is explained, this dryness indicating a descent from aloft rather than an inflow for some distance over the sea.

The only systematic study of the sea breeze yet made, so far as known to the writer, was that undertaken by the New England Meteorological Society in the summer of 1887. The results derived from that one season's work, interesting and valuable in themselves, serve to show how much more might be accomplished by similar investigations elsewhere. There remain many points which need further study. Simple observations of the height of the land and sea breezes and of the return upper currents by means of captive balloons, and barometric records from stations a few miles inland, on the shore and on

islands offshore, would afford excellent tests of Seemann's theory. Such observations could be very easily made and the work is certainly most attractive.

Although in considering land and sea breezes, we are dealing with one of the less important meteorological phenomena, it is well, in closing this review, to call attention to the correlation of these breezes with other winds of more importance but of similar origin. The warming and cooling of the land which gives rise to the on- and offshore breezes we have been studying, is a diurnal affair depending on the warming by the sun's heat by day and the cooling by radiation and conduction by night. The changes of temperature and of pressure to which these breezes are due, are not, however, restricted to the coastal region, as the breezes themselves are, but extend all over the land surface. Now what we see as a diurnal phenomenon in the case of the land and sea breezes, we see as a seasonal phenomenon in the increase of pressure over the continents in winter and the decrease of pressure in summer, whereby they become alternately areas of high and low pressure and their wind circulation changes accordingly. A winter continent, therefore, has outflowing winds, and a summer continent has inflowing winds, and these, which may be called continental winds, combine with the larger class of terrestrial winds to form the general winds of the earth. The class of seasonal, or continental winds is simply a larger example of the smaller class of land and sea breezes. In the former case the continuance of the temperature and pressure conditions is for some months at a time; in the latter it is for a few hours only. In the former case, therefore, a general continental circulation of the winds can be established; in the latter there is only time for the establishment of a local and incomplete circulation.

NOTE.—ADDED JULY 24, 1893.

Since preparing the above review, the writer has received a copy of Dr. Otto Krümmel's "Geophysikalische Beobachtungen der Plankton-Expedition" (Kiel & Leipzig, 1893), in which are presented the results derived from the meteorological observations made by Dr. Krümmel during the scientific exploring voyage of the Plankton Expedition in the Atlantic Ocean during July–November, 1889. Dr. Krümmel calls attention to a point in connection with sea breezes which is worthy of note here, and of careful observation in any future investigation of this class of winds. He noticed that during the time the vessel *National* was anchored off Para the sea breeze was most marked during a flood tide. This fact the author finds referred to in several previous accounts of land and sea breezes. In Staff Commander James Penn's "Sailing Directions for the West Coasts of France, Spain and Portugal" (London, 1867, p. 273) it is stated that at Cadiz—

> The sea breezes vary from west to north-northwest and are generally strongest at the full and change of the moon, when they not unfrequently blow during the whole night. They set in most commonly with the flood * * *.

Further, in the "Annalen der Hydrographie," 1887, p. 164, the captain of the German cruiser *Habicht* states that at Kamerun the sea breeze is the strongest when the flood tide comes in the afternoon. The explanation of this fact is found in the mechanical raising, by the rising tide, of the mass of air lying over the water near the shore, thus causing stronger gradients aloft and consequently a more active circulation.

REFERENCES.

(1) **Davis, W. M., L. G. Schultz, & Ward, R. DeC.** An Investigation of the sea breeze. Annals, Astron. obsy. Harv. Coll., **21**, pt. 2, Cambridge, Mass. 1890. p. 215–263. f°.
(2) **Dampier, William.** Voyages and descriptions. London, 1705. *See also* Dampier's voyages ... edited by John Masefield. 2 v. E. P. Dutton & Co., New York, 1906. 8°. v. **2**, pt. 3, chapt. 4, pp. 251–264.
(3) **Buchan, A.** Introductory textbook of Meteorology. Edinburgh, &c. 1871. p. 132, § 334.
(4) **Mühry.** Über die Theorie der Land- und See-Winde. Ztschr. d. Oesterr. Ges. f. Meteorol., 1868, **3**, p. 475.
(5) **Laughton.** Physical geography in its relation to the prevailing winds. 1873. 400 p. 8°.
(6) **Köppen, W.** *In* Meteorol. Ztschr., 1884, **1**. Jhrg., p. 40.
(7) **Seemann.** Über Land- und See-winde und deren Verlauf. Wetter, Berlin, 1884, p. 79, 101, 124.
(8) **Chambers.** Meteorology of the Bombay Presidency. 1879. p. 109.
(9) **Hazen, Henry A.** Report on wind velocities at the Lake crib and at Chicago. Washington. 1883. (U. S. Signal service notes, No. VI.)
(10) **Hann, Julius.** Handbuch der Klimatologie. 3te Aufl. Stuttgart. 1908–1911. 3 v. 8°. v. **1**, p. 151.
(Same) translated by Ward. New York. 1903. p. 155.
(11) **Köppen, W.** *In* Ztschr. Oesterr. Gesellsch. f. Met., Wien, 879, **14**, p. 377.

1

GRAPHICAL INTEGRATION OF FUNCTIONS OF A COMPLEX VARIABLE WITH APPLICATIONS.

By S. DOUGLAS KILLAM, Ph. D.

[Dated, University of Alberta, November 5, 1913.]

Many problems in mathematics can be solved more simply by graphical than by analytical methods; especially is this true when the problem is presented graphically, and we wish a graphical representation of the solution. The object of this present paper is to give some of the results of graphical integration of functions of a complex variable as obtained by the author and published in part in his Dissertation (1).

Functions of a complex variable arise in a great many problems of mechanics and physics. In these the graphical method of solution is of great advantage, and gives results in which the errors of graphic methods are so small that they may be disregarded.

As an introduction to the integration of functions of a complex variable I wish to give a short and accurate method of graphically integrating functions of a real variable (2), since graphical integration of functions of a complex variable can be reduced to repeated successive graphical integrations of functions of a real variable.

In this paper I shall only consider the mathematical side of the problem and give one or two examples worked out in detail, so that the physicist or student of applied mechanics can easily apply my method to other problems.

1. GRAPHICAL INTEGRATION OF FUNCTIONS OF A REAL VARIABLE.

A function $f(x)$ of the real variable x can be represented graphically in the x,y plane. On the x axis (fig. 1) we take a number of points $x_1, x_2, x_3, \cdots$; through them draw the ordinates cutting the curve $f(x)$ in the points $a, A, B, C, \cdots$. We now draw M_1c parallel to the x axis so that the area of aM_1b equals the area of bcA. In the same way we draw $de; fg; hi; \cdots$ and produce them to cut the y axis in the points $M_1, M_2, M_3, M_4, \cdots$. Take a point P on the x axis so that Px_1 shall equal unity; and join P to these points $M_1, M_2, M_3 \cdots$. Now the

area under the curve $f(x)$ equals the area under the "step-curve" $aM_1bcdefg \cdots$. We obtain the integral of the broken line by starting from x_1 and draw lines parallel to the lines PM_1, PM_2, $\cdots$ meeting the

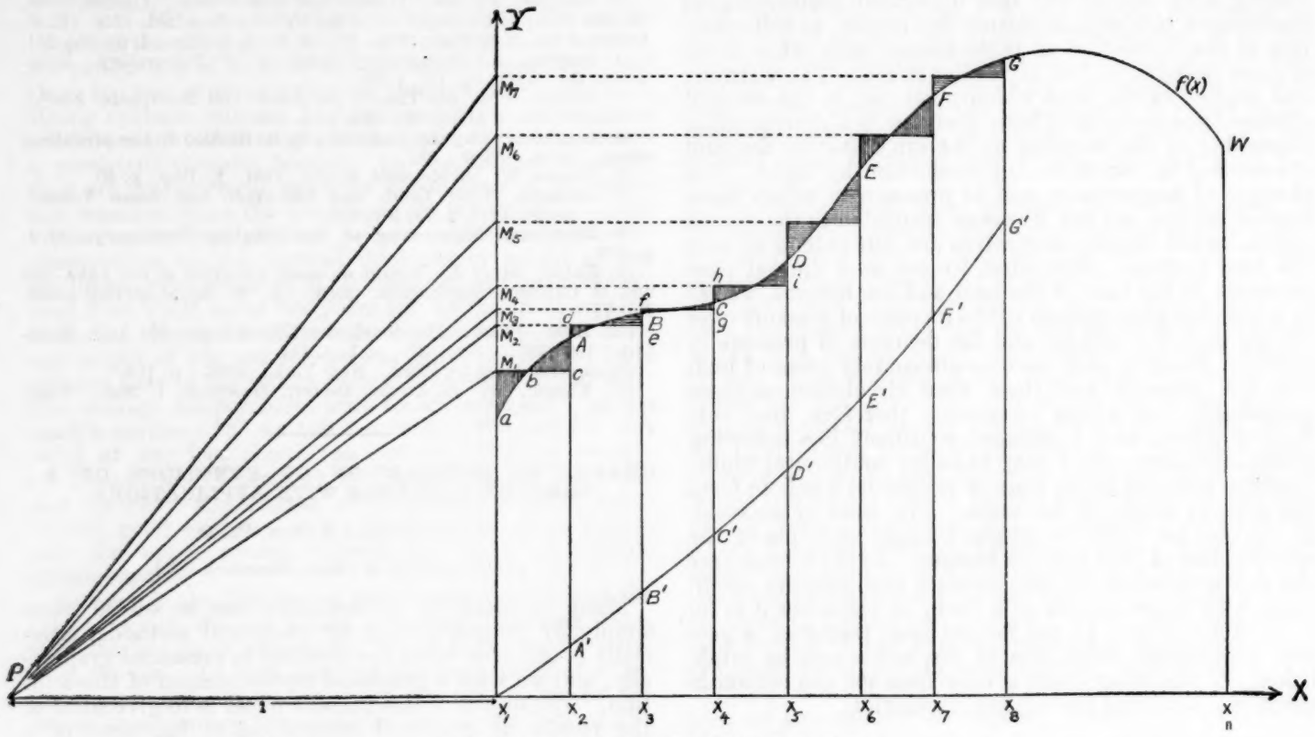


FIG. 1. Graphical representation of $f(x)$ in the x,y plane.

ordinates drawn through the points x_2, x_3, x_4, $\cdots$ at the points A',B',C', $\cdots$. This broken line $A'B'C' \cdots$ gives the values of $\int_0^x f(x)dx$ for $x=x_1$; $x=x_2$; $\cdots$. In order to obtain the graph of the curve for all values of x we draw a smooth curve through the points $A'B'C' \cdots$. If our points x_1, x_2, x_3, $\cdots$ are drawn close enough together the broken line $A'B'C'D' \cdots$ closely approximates the curve $\int f(x)dx$. The Integraph (a machine for mechanically integrating curves) may be used for integrating the graph of the curve $\int f(x)dx$; but I have found by careful work with both methods that the graphical method of integration is shorter and more accurate. With reasonable care and the use of a large scale the results obtained will be exact enough for the solution of all problems arising in applied mathematics.

2. GRAPHICAL INTEGRATION OF FUNCTIONS OF A COMPLEX VARIABLE.

A function $w=f(z)$ of the complex variable $z=x+iy=re^{i\phi}$ is given graphically by the conformal representation of the z plane on the w plane. We can choose the net of curves in the z plane in any way we like; but in order to have a control over our analytical work we choose a system of orthogonal curves

$$r=r_n(n=1,2,3, \cdots)$$

and

$$\phi=\phi_n(n=1,2,3, \cdots)$$

where r_n and ϕ_n are such values that the z plane is covered by a net of small squares as in figure 2.

In accordance with the laws of conformability, our function $f(z)$ will be represented in the w plane by a system of orthogonal curves which cover the plane with a net of small squares (see fig. 3).

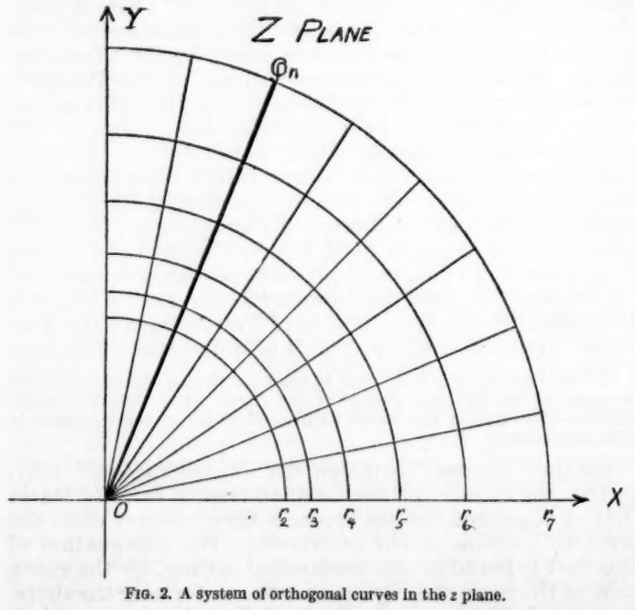


FIG. 2. A system of orthogonal curves in the z plane.

We now seek a graphical representation of the function

$$Z=\int_0^z f(z)dz$$

in the Z plane; i. e., we seek the curves $r=r_n$ and $\phi=\phi_n$

in our Z plane. If we integrate $f(z)$ from $z=0$ to $z=r_n e^{i\phi_n}$ along the curve or path $\phi=\phi_n$ we have

$$Z=X+iY=\int_0^{z_n} f(z)dz$$
$$=\int_0^{r_n}\Big[u(r,\phi_n)+iv(r,\phi_n)\Big]d(re^{i\phi_n})$$
$$=e^{i\phi_n}\Big[\int_0^{r_n}u(r,\phi_n)dr+i\int_0^{r_n}v(r,\phi_n)dr\Big] \qquad (1)$$

where

$$f(z)=u(r,\phi_n)+iv(r,\phi_n).$$

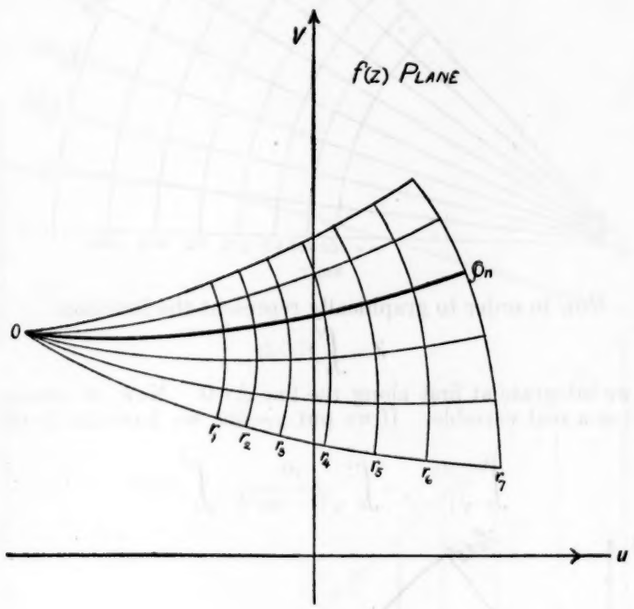


FIG. 3.

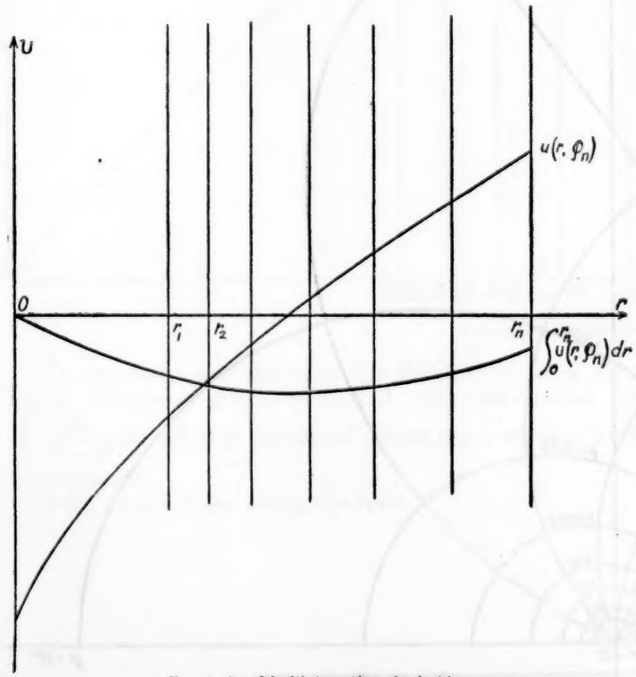


FIG. 4. Graphical integration of $u(r,\phi_n)$.

Now $u(r,\phi_n)$ is a function of the real variable r and can be represented graphically in a u,r plane. Similarly $v(r,\phi_n)$ can be represented in a v,r plane. We now integrate graphically by the method of §1 to obtain the values of

$$\xi=\int_0^{r_n} udv$$

and

$$\eta=\int_0^{r_n} vdr \quad (n=0,1,2,3,\cdots)$$

(see figs. 4 and 5).

In order to draw the graphs of the curves

$$u(r,\phi_n) \text{ and } v(r,\phi_n)$$

we obtain the values of u and v which correspond to

$$r_n (n=1,2,3,\ldots)$$

from figure 3.

In our

$$Z=\int_0^z f(z)dz \text{ plane}$$

we draw the axes $\int udr$ and $\int vdr$ so that the angle between the X axis and the $\int udr$ axis equals ϕ_n (see fig. 6).

From equation (1) we see that the factor $e^{i\phi_n}$ means that the X axis must rotate through an angle of ϕ_n in order to coincide with the ξ axis. In the ξ,η plane we mark the points $r_1, r_2, r_3, \cdots$ with the coordinates ξ and η. We get these values from the graphical integration of the functions $u(r,\phi_n)$ and $v(r,\phi_n)$ (see figs. 4 and 5). They can be transferred over to our new Z plane by measurement; or, by having our ξ,η plane drawn on transparent paper, we can mark off the points $r_1,r_2,r_3,\cdots$ without measuring the values of ξ and η. This latter method eliminates a small error of measurement.

Through the points $r_1, r_2, \cdots$ we draw a smooth curve which is the required graphical representation of the curve $\phi_n=\phi_n$ in the Z plane.

In the same way we obtain the curves $\phi=\phi_1$; $\phi=\phi_2$; $\cdots$. Through the points r_n on each curve $\phi=\phi_n$ we

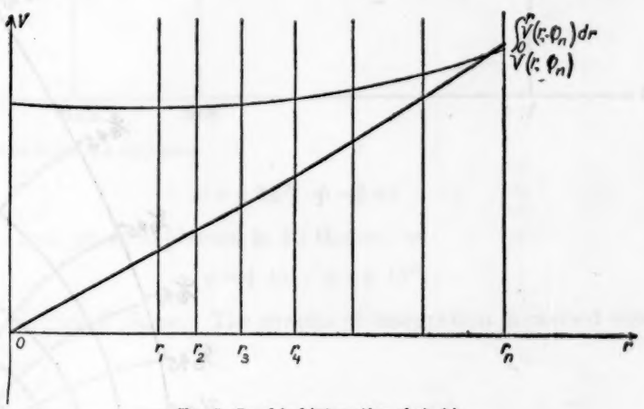


FIG. 5. Graphical integration of $v(r,\phi_n)$.

draw a smooth curve and obtain a net of small squares covering the Z plane which is the graphical representation of the function

$$Z=\int_0^z f(z)dz.$$

3. GRAPHICAL INTEGRATION OF $f(z)=(1-z^4)^{-\frac{1}{2}}$.

Let $f(z)$ in the preceding section be $(1-z^4)^{-\frac{1}{2}}$ then we have the special problem of the graphical integration of $(1-z^4)^{-\frac{1}{2}}$.

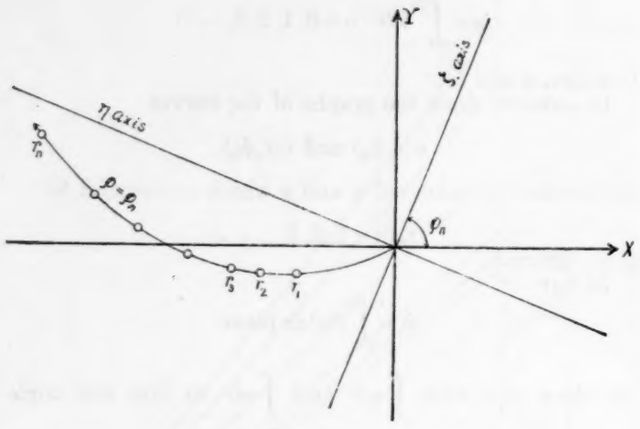


FIG. 6.

We represent

$$z=x+iy=re^{i\phi} \text{ in the } z \text{ plane}$$

by the curves $r=r_n(n=0,1,2,\cdots)$ and $\phi=\phi_n$. (Figure 7). These curves are transformed by the function

$$f(z)=(1-z^4)^{-\frac{1}{2}}.$$

into the curves $r=r_n$ and $\phi=\phi_n$ $(n=1,2,3,\cdots)$ in the $f(z)$ plane (see figure 8).

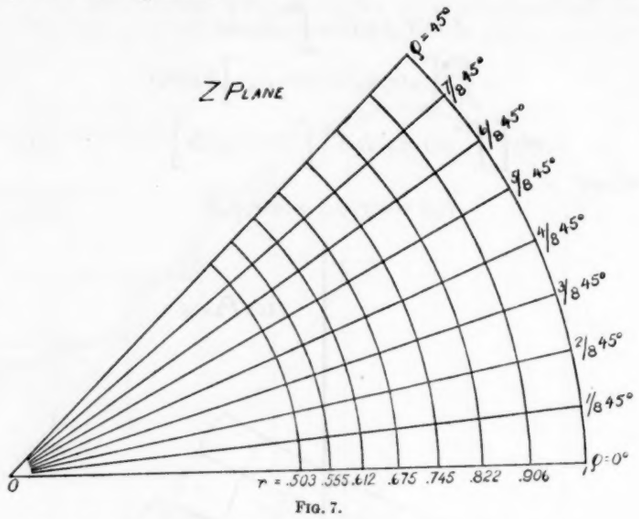


FIG. 7.

Now in order to graphically represent the function

$$Z=\int_0^z f(z)dz$$

we integrate at first along the line $\phi=0$. Now, of course z is a real variable. If we put $z=\sin t$, we have for $\phi=0$

$$\int_0^1 \frac{dz}{\sqrt{1-z^4}}=\int_0^{\frac{\pi}{2}} \frac{dt}{\sqrt{1+\sin^2 t}}=\int_0^{\frac{\pi}{2}} f(t)dt.$$

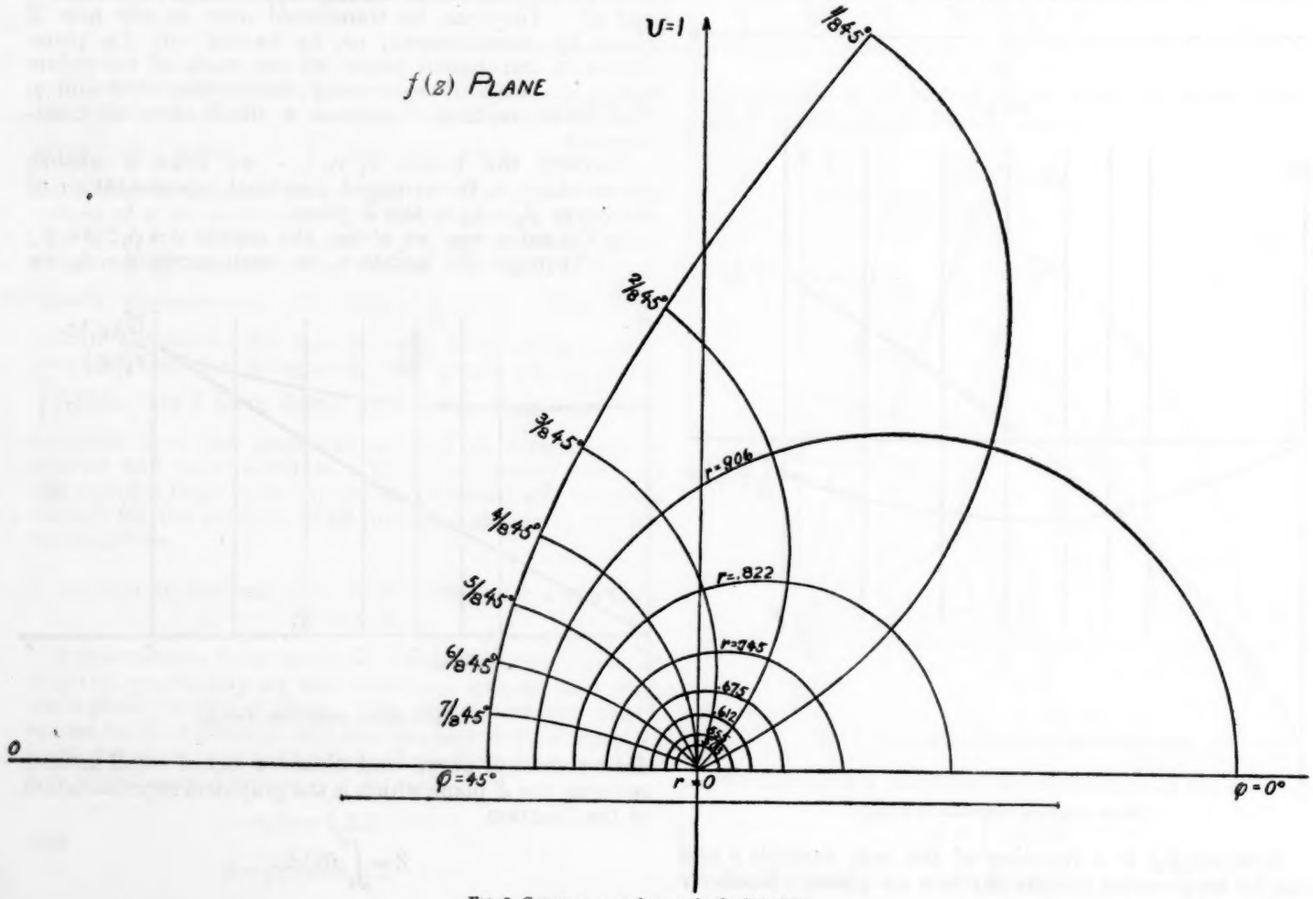


FIG. 8. Curves $r=r_n$ and $\phi=\phi_n$ in the $f(z)$ plane.

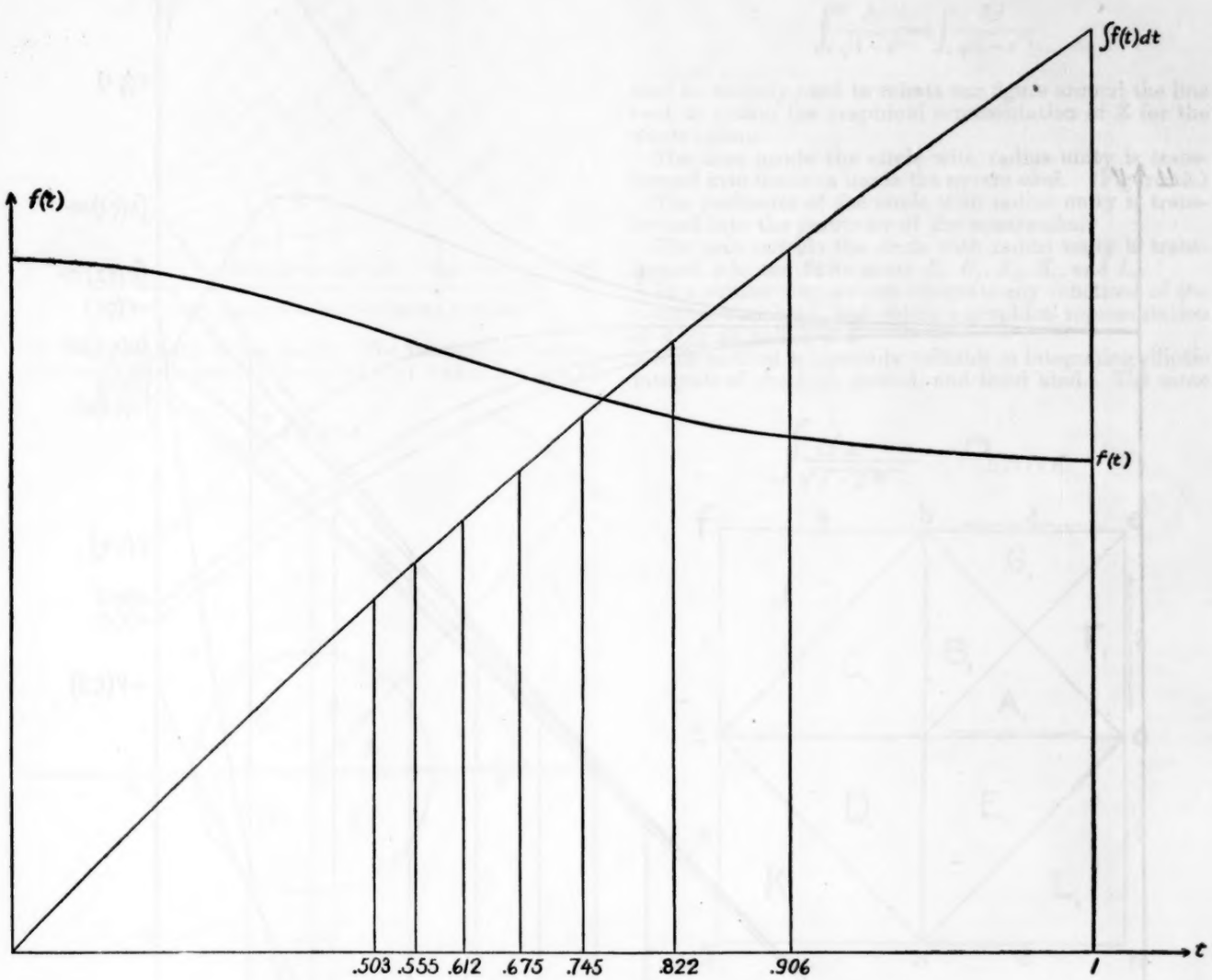


FIG. 9. Graphic representation of $f(t)$ in a $f(t),t$ plane.

We represent the function $f(t)$ graphically in a $f(t),t$ plane; integrate graphically and get the values of $\int_0^z \frac{dz}{\sqrt{1-z^4}}$ for all real values of z between $z=0$ and $z=1$ (see figure 9).

Next we integrate along the lines

$$\phi = \tfrac{1}{8}\,45°;\ \phi = \tfrac{2}{8}\,45°;\ \cdots$$

and get as explained in §2 the curves

$$\phi = \tfrac{1}{8}\,45°;\ \phi = \tfrac{2}{8}\,45°;\ \cdots$$

in our Z plane. The graphical integration is carried out

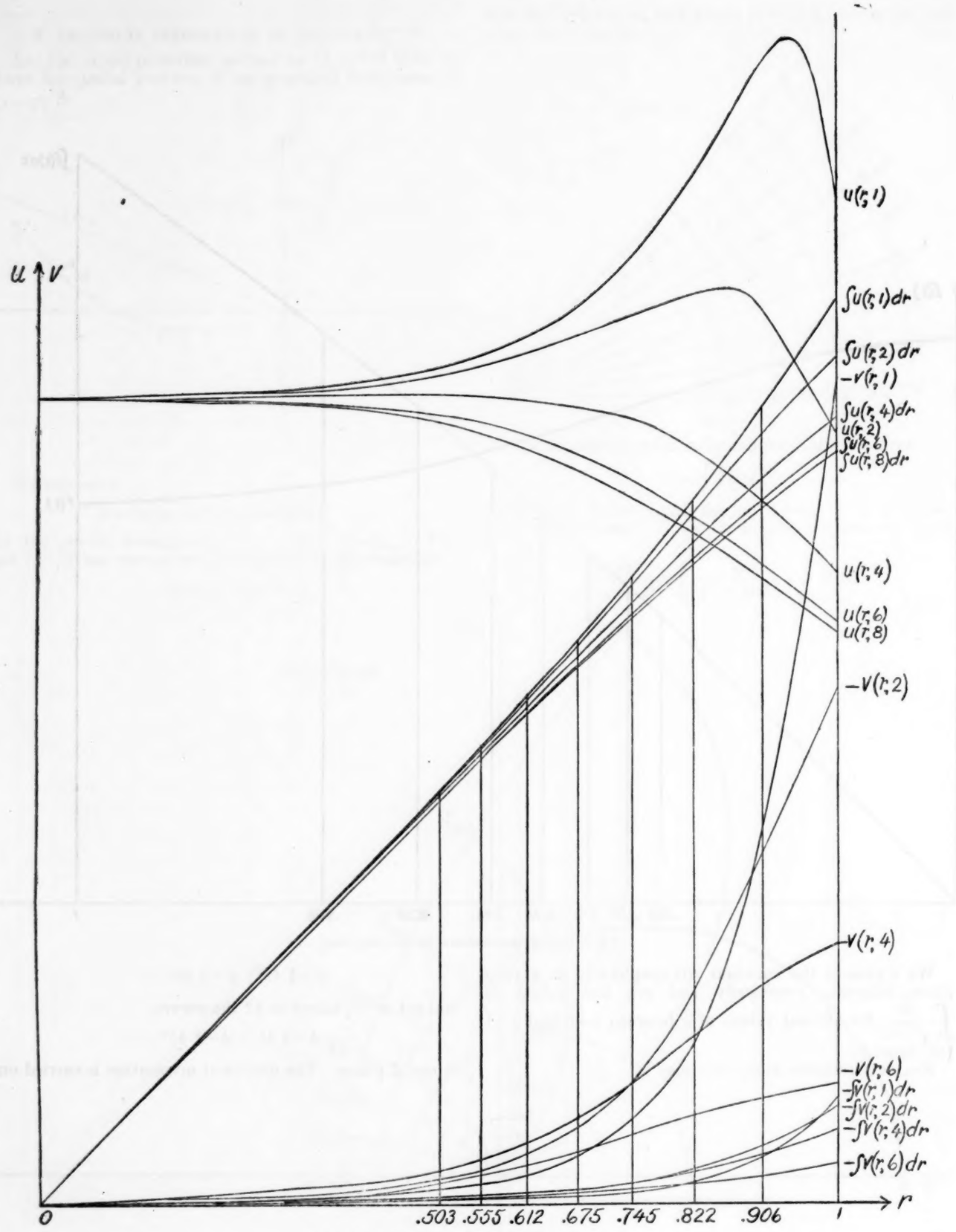


FIG. 10. Graphical integration along $\phi = \frac{1}{8}$ 45°, $\phi = \frac{1}{4}$ 45°, etc.

as in figure 10 and the results shown graphically in figure 11.

We now have in the Z plane the graphical representation of our function Z for all values of z in the first octant

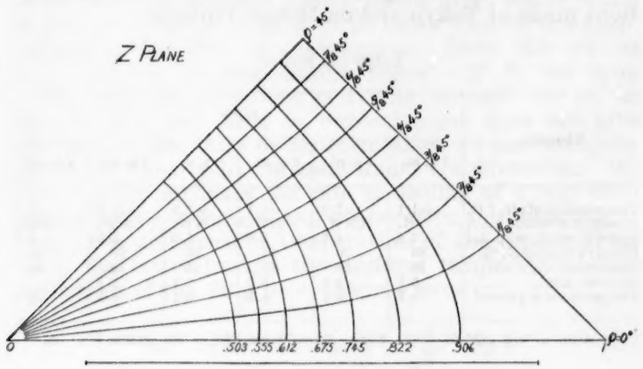


FIG. 11. Result of graphical integration of $f(t)$ in a $f(t),t$ plane.

of the circle with radius unity. The function is continuous everywhere even at the point $z=1$ which is a branch

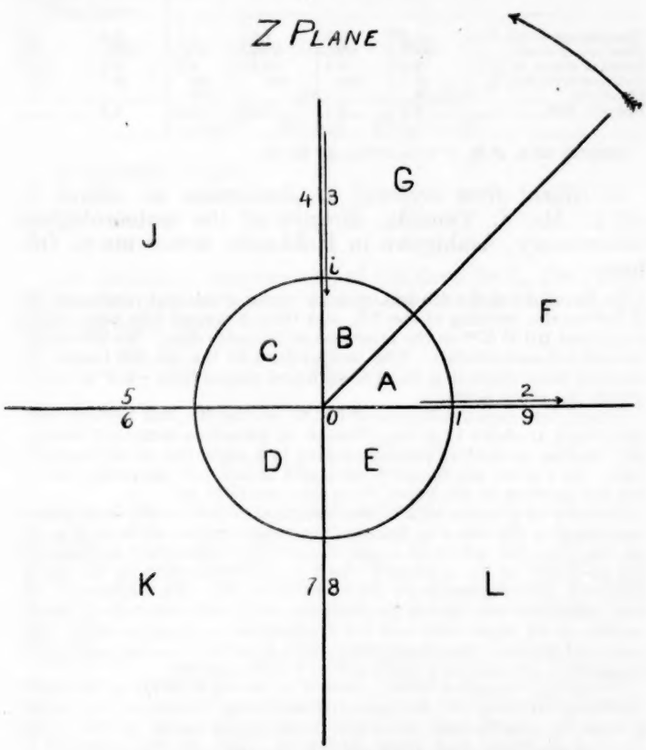


FIG. 12. Illustrating "rebattement" for the function in the second octant.

point of the first order. We obtain the representation of our function for the second octant by simply rebatting [from the French geometrical term "rebattement" "The rotation of a plane about its intersection with a plane of projection, until it coincides with that plane"] around the line $\phi=45°$. In the same way we obtain the representation in the 3d, 4th, · · · 8th octant. (See figure 12). The areas A, B, C, D, E, correspond to the areas A_1, B_1, C_1, D_1, E_1. The points ± 1 and $\pm i$ are branch points of the first order. If we let $z=z'^{-1}$ we have

$$\int_0^\infty \frac{dz}{\sqrt{1-z^4}} = i\int_0^1 \frac{dz'}{\sqrt{1-z'^4}}$$

that is, we only need to rebatt our figure around the line $r=1$ to obtain the graphical representation of Z for the whole z plane.

The area inside the circle with radius unity is transformed into the area inside the square *abcd*. (Figure 13.)

The perimeter of the circle with radius unity is transformed into the perimeter of the square *abcd*.

The area outside the circle with radius unity is transformed into the finite areas E_1, G_1, J_1, K_1, and L_1.

In a similar way we can integrate any functions of the complex variable z, and obtain a graphical representation of Z for all values of z.

This method is especially valuable in integrating elliptic integrals of the first, second, and third kind. The same

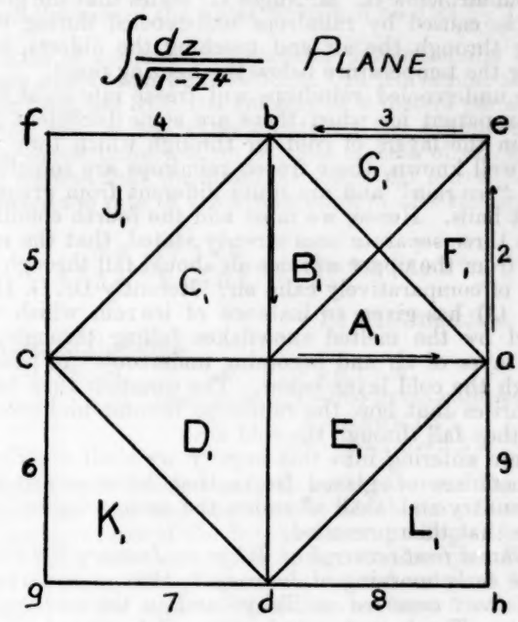


FIG. 13.

methods can be used for solving all problems involving graphical integration of functions of a complex variable that arise in mechanics and applied mathematics.

REFERENCES.

(1) **Killam, S. Douglas.** Ueber graphische Integration von Funktionen einer Komplexen Variabeln mit speziellen Anwendungen. Diss.—Göttingen, 1912.

(2) **Massau.** Mémoire sur l'intégration graphique.

NOTES ON THE FORMATION OF GLAZED FROST.[1]

By T. OKADA.

[Dated, Central Meteorological Observatory, Tokyo, Apr. 4, 1913.]

1. *Introduction.*—The glazed frost is a transparent smooth coating of ice covering trees, or buildings, or the ground, and is usually caused by rain which freezes as it touches these objects and thus covers them with a coating of transparent ice. The formation of this rare phenomenon has been studied by several scientists. Among others, Dr. Meinardus (1) investigated thoroughly the ice storm that occurred over middle and eastern Germany on October 20, 1898, and stated the three conditions necessary for the production of the glazed frost, i. e.:

(1) In the upper air there must be a stratum of warm air having the temperature above 0° C.

(2) This warm layer should be laden with moisture, and must have the vertically upward component of motion so that condensation of vapor takes place in it.

(3) Below this warm layer there must be another layer of the temperature below 0° C.

Dr. Meinardus thinks that raindrops from the upper layer of warm air become undercooled as they fall through the cold air below it. M. Angot (2) states that the glazed frost is caused by raindrops undercooled during their falling through the air and touching the objects, both having the temperature below the freezing point.

The undercooled raindrops will freeze into solid balls of transparent ice when there are some turbulent motions in the layers of cold air through which they fall. As is well known, these frozen raindrops are sometimes called "ice rain" and are quite different from graupeln or soft hails. Hence, we must add the fourth condition to the three separate ones already stated, that the raindrops from the upper warmer air should fall through the layers of comparatively calm air. Recently Dr. G. Hellmann (3) has given an instance of ice rain which was formed by the melted snowflakes falling through the warm layer of air and becoming undercooled in passing through the cold layer below. The question then naturally arises that how the raindrops become undercooled when they fall through the cold air.

Before entering into this inquiry we shall describe a few instances of glazed frosts that have occurred in this country and shall examine the meteorological conditions that then prevailed.

2. *Glazed frost occurred at Tokyo on January 8, 1902.*—On the early morning of January 8, 1902, a remarkable glazed frost occurred at Tokyo and in the neighboring districts. The branches and leaves of trees and all exposed objects were covered with transparent ice of a thickness of about 5 to 10 millimeters. The ground was also covered with a coating of ice to considerable danger to pedestrians. The temperature of air remained 1 degree below the freezing point, but that of the surface of ground was a little above it. The winds blew from the northwest, the force being moderate. Rain fell since 2 a. m. of the day. At about 4 a. m. it turned into sleet. We have no observations from the upper air at Tokyo. But fortunately we have hourly meteorological observations taken on the summit of Mount Tsukuba (870 meters high) at a distance of 65 kilometers to the northeast of Tokyo. From these observations we know that at the height of 870 meters above sea level the strong winds from the southwest were blowing and rain was falling slightly. The temperature of air was above the freezing point and was about 3 or more degrees higher than that at Tokyo. Hence, we may assume, in all probability, that warm winds from the southwest were also blowing in the upper level at Tokyo, and rain was falling from this warmer air. We give below extracts of the observations made at Tokyo and on Mount Tsukuba.

Tokyo (21 meters).

Element.	Hour.					
	3 a. m.	4 a. m.	5 a. m.	6 a. m.	7 a. m.	8 a. m.
Temperature of air, ° C.	−1.1	−1.0	−1.1	−1.2	−1.2	−1.2
Direction of wind	N.	NNW.	NW.	NW.	NW.	NW.
Speed of wind, m. p. s.	2.8	4.6	5.4	5.0	3.5	4.3
Relative humidity, %	83	90	93	95	97	95
Cloudiness	10	10	10	10	10	10
Rainfall, mm	0.1	2.8	5.2	4.3	2.7	
Temperature of ground	0.1	0.1	0.1	0.1	0.1	0.1

Remarks: ⌴° a.p., ●° 2a—2:30a, 2:45 a—●, ✳° 4:10a—●°, ✳° 6a—6:10a, T°, ~ a.

Tsukuba (870 meters).

Element.	Hour.					
	3 a. m.	4 a. m.	5 a. m.	6 a. m.	7 a. m.	8 a. m.
Temperature of air, ° C.	−1.2	0.7	1.0	2.3	2.8	2.2
Direction of winds	SW.	SW.	SW.	SW.	SW.	SW.
Speed of winds, m. p. s.	8.9	9.2	10.2	9.8	9.3	12.7
Relative humidity, %	96	100	100	100	98	95
Cloudiness				10		
Rainfall, mm	0.2	0.5	0.7	0.6	0.3	

Remarks: ≡² a., 🌂 5a., ✳°—1a., 2:10 a—●° 3a—7a.

3. *Glazed frost occurred at Asahigawa on March 7, 1914.*—Mr. J. Yamada, director of the meteorological observatory, Asahigawa in Hokkaido, writes me as follows:

On the night of the 6th instant snow began to fall and continued till $1^h\ 45^m$ on the morning of the 7th, and then it turned into rain, which continued till $5^h\ 57^m$ on the afternoon of the same day. We also experienced a frozen rainfall. The temperature of the air fell below the freezing point since 10 p. m. of the 6th and ranged from −0.8° to −2.2° during the rainy hours.

Glazed frost began to appear at 6 a. m. on the 7th, and became fully developed at about 11 a. m. Thence its formation remained stationary, making no further progress, owing to a slight rise of air temperature. At 5 p. m. the temperature began to fall, but the coating of ice did not increase in thickness, since rain ceased to fall.

In order to give an idea of the thickness of ice on the branches of trees we give the following result of my measurements made at 11 a. m. on the 7th. On a twig of a tree measuring 3 millimeters in diameter the thickness of ice deposited was 2 to 2.2 centimeters on the upper side, and 1.3 centimeters on the lower side of it. The thickness of ice on a telephone wire having the diameter of 2.5 millimeters is 1.2 centimeters on its upper side and 0.5 centimeter on its lower side. The roofs and walls of this observatory were covered with the coating of transparent ice having a thickness of 0.6 centimeter.

During the formation of the glazed frost, strong winds from the north continued to blow, the maximum speed being 7.9 m.p.s. In consequence the glazed frost developed most conspicuously on the north sides of buildings and other substances. But on the branches of trees and telephone wires the ice grew mostly on their upper sides, so that the sections of the ice coating were ellipses, excentric with them. We also observed many icicles hanging from the branches from trees. The diameters of these icicles range from 0.4 to 0.7 centimeter and their length from 3 to 5 centimeters. Owing to the heavy deposit of ice, telephone and telegraph wires in this town were broken in many places. Many electric poles were prostrated. Electric communications in this town were suspended for the whole day. Branches of trees were broken down, and the trunks of larches and poplars were bent down owing to the overloading of the ice coating.

On the afternoon of the 8th the weather cleared up, and the sun shone upon the transparent coating of ice. It remained unmelted till the evening of the 10th.

4. *Formation of glazed frost.*—As we have explained in the first paragraph the point to be explained in the theory

[1] *Reprinted from* Journal, Met. Soc. of Japan, May, 1914, 33d year, No. 5, pp. 15-24.

of the formation of glazed frost is how raindrops become undercooled in passing through a layer of cold air. They may be cooled by conduction and evaporation as it is tacitly assumed in the current theory. Mr. E. Gold (4) calculated the rate of cooling of a drop 2 mm. in diameter and found that the rate is a degree for every meter of fall if the temperature of air is 2° C. below that of the drop, neglecting the effect of evaporation. From this we see that with an air temperature below −2° C. the drop would lose sufficient heat in falling through 100 m. to turn it into ice. But as our colleague does not give the method and data of his calculation we can not apply his result directly to the cases under consideration. So, let us newly estimate the rate of cooling of a rain drop taking both conduction and evaporation into account.

Let the difference of temperature of the drop and air be θ, the latter having the uniform temperature. Let the radius of the drop be r, then we have

$$-4\pi r^2 E\theta\, dt - 4\pi r^2 ql\, dt = +\frac{4}{3}\pi r^3 c\rho\, d\theta \qquad (1)$$

where E is the coefficient of external conductivity, q the rate of evaporation (per cm.² of the surface), c the specific heat, ρ the density of the drop, and l the latent heat of vaporization.

We have

$$(E\theta + ql)dt = -\frac{c\rho}{3} r d\theta,$$

$$-\frac{3}{c\rho r}dt = \frac{d\theta}{E\theta + ql} = \frac{1}{E}\frac{d(E\theta)}{(ql + E\theta)}.$$

Integrating we get

$$\theta = \frac{C}{E} e^{-\frac{3E}{c\rho r}t} - \frac{ql}{E}.$$

Let the initial temperature of the drop be θ_0, the origin of the temperature scale being the temperature of the external air. Then

$$\theta_0 = \frac{C}{E} - \frac{ql}{E}$$

therefore

$$\theta = \left(\theta_0 + \frac{ql}{E}\right) e^{-\frac{3E}{c\rho r}t} - \frac{ql}{E} \qquad (2)$$

Of the rate of evaporation of raindrops we are quite ignorant. In the annual meeting of the Austrian Meteorological Society for 1896 Dr. W. Trabert (5) read a paper on this subject, but his paper seems to have been published neither in the organ of the society nor in other scientific journals.

In order to get an idea of the magnitude of evaporation we have observed the loss of weight of a water drop which was placed on a thin cover glass coated with paraffin wax. The glass with the drop was placed in a chamber in which the humidity and temperature were kept nearly constant.

We give below the result of our measurements:

Time	Weight of the drop	Radius of the drop
11 h. 19 m.a.	11.7 mg.	1.40 mm.
2 00 p.	6.0 mg.	1.12 mm.
3 26 p.	3.7 mg.	0.96 mm.
4 00 p.	2.9 mg.	0.88 mm.

Since the rate of evaporation of the water drop is proportional to its surface, the radius of the drop decreases at a constant rate with time. In our measurements this rate is 0.002 mm. per minute or 0.000033 mm. per second. Hence we have

$$q = 3.3 \times 10^{-6} \times 1^2 \text{ mm. per second.}$$

During the experiments the deficiency of saturation of air in the chamber in which the water drop was placed was 3 mm. and there was no sensible motion of air.

Now let us estimate the temperature of raindrops which caused the remarkable glazed frost at Tokyo. Assume that the height of the air stratum from which the rain fell at Tokyo in that case was about 870 meters and the temperature of it was 2°C. Since the temperature of air near the surface of the ground at Tokyo was −1.2°C. it is not improbable to assume that the mean temperature of cold air stratum which stretched above the city up to 870 mm. [870 meters?] was −1.5°C. at that time.

Again let us assume that the diameter of the raindrop was 2 mm., and the speed of falling is 6 meters per second. Then the time of falling is 870/6 = 145 seconds.

The rate of evaporation of water is proportional to the deficiency of saturation of air. In the case under consideration we have assumed that the relative humidity is 90 per cent and the temperature of air is −1.5°C., therefore the deficiency of saturation is only 0.4 mm. Hence the rate of the water drop will be $q \times \left(\frac{0.4}{3.0}\right)$. But the rate of evaporation increases proportionally to the square root of the wind velocity. In the actual case the water drop fell with the velocity of 6 meters per second. In the case of the experiments on the evaporation of water drops there was no sensible motion of air, but we may assume that the speed 0.1 meter per second or less.

Hence the rate of the evaporation of the raindrop will be

$$q \times \frac{0.4}{3.0} \times \sqrt{\frac{1+6}{1+0.1}} = q \times \frac{1}{3} = 3.3 \times 10^{-6} \times \frac{1}{3}$$
$$= 1.1 \times 10^{-6} \text{mm./sec.}$$

We take therefore

$t = 145$ sec.	$r = 0.1$ cm.
$q = 1.1 \times 10^{-6}$ mm. p. sec.	$l = 600$ gram-calories
$\rho = 1$	$E = 2.66 \times 10^{-4}$
$c = 1$	$\theta_0 = 2 + 1.5 = 3.5$°C.

Before calculating the final temperature of the falling drop let us first find the time at which the difference of the temperatures of the drop and surrounding air becomes zero. This difference changes sign at that moment, and then we must change the meaning and value of E.

Let t' be the required time then we have $\theta = 0$ at $t = t'$. Hence we get

$$0 = \left(\theta_0 + \frac{ql}{E}\right) e^{-\frac{3E}{c\rho r}t'} - \frac{ql}{E}$$

From this we have

$$t' = \frac{c\rho r}{3E}\left\{\log\left(\theta_0 + \frac{ql}{E}\right) - \log\left(\frac{ql}{E}\right)\right\} \qquad (3)$$

Now

$$\theta_0 + \frac{ql}{E} = 3.5 + \frac{1.1 \times 10^{-6} \times 600}{2.66 \times 10^{-4}} = 3.5 + 2.5 = 6°$$

$$\frac{ql}{E} = 2.5°\text{C.}$$

$$\frac{c\rho r}{3E} = \frac{1 \times 1 \times 0.1}{3 \times 2.66 \times 10^{-4}} = 125.3$$

Hence

$$t' = 125.3 \times (1.79 - 0.92) = 125.3 \times 0.87 = 109 \text{ seconds.}$$

In finding the final temperature of the rain drop we introduce a new quantity E' instead of E and put θ_0 equal to zero in the equation giving the value of θ. Then we get

$$\theta = \frac{ql}{E'}\left(1 - e^{\frac{3E'}{c\rho r}t''}\right)$$

in which we shall put $145 - 109 = 36$ for t''. In actual calculation we put E equals to E' in absolute values, since we have, for the present, no adequate value for E'.

Then we have

$$\theta = 2.5 \times \left(1 - e^{\frac{36}{125.3}}\right)$$

$$= 2.5 \times (1 - 1.33) = -2.5 \times 0.33 = -0.8°\text{C.}$$

This is of course the same result which we obtain by putting $t = 145$ in equation (2).

Hence the final temperature of the drop will be

$$-0.8 - 1.5 = -2.3° \text{ C.}$$

From the above calculation we see that in the case under consideration the conduction and evaporation of rain drops falling through ice-cold layers of the atmosphere will be sufficient to cool them many degrees below the freezing point, and to cause them to cover the objects with the coating of ice when they come to touch these objects. In some cases in which the air is too moist the drops of rain cool to the dew point of the air after they fall a few meters from their mother clouds, and condensation begins instead of evaporation on their surfaces. Hence the formation of glazed frost is not probable in such cases.

In conclusion I express my sincere thanks to Drs. K. Nakamura and S. Fujiwhara of the Central Meteorological Observatory for their kind suggestions in the preparation of this note, and also to Mr. J. Yamada of the meterological observatory, Asahigawa for his kindness in sending me the report of the remarkable glazed frost given in the text.

REFERENCES.

(1) **Meinardus, W.** Der Eisregen vom 20. Oktober 1898 über Mittel- und Ost-Deutschland. Wetter, Berlin, 1898, p. 253.
(2) **Angot, A.** Traité élémentaire de météorologie. Paris, 1899. p. 257.
(3) **Hellmann, G.** Ueber die Entstehung von Eisregen. Bericht. d. K. preuss. Akad. Wiss., Berlin, 1912, p. 1048.
(4) **Gold, E.** Glazed frost. Symons's met. mag., London, 1914, **48**, p. 233.
(5) **Trabert, W.** Verdampfung von Regentropfen. Meteorol. Ztschr., Wien, 1896, **13.** Jhrg., p. 323.

HAZE OF MAY 13 TO MAY 17, 1914.

From the 13th to the 17th of May, in that portion of the United States extending from Virginia north to Maine and west to South Dakota, numerous observers reported the presence of haze which, on investigation, proves to have been principally of a reddish brown tint, apparently due to the dissemination of dust from forest fires. It does not seem to have been due to any special distant volcanic eruption as imagined by some. At Mount Weather, Va., the haze was very dense on and after May 19, but Prof. H. H. Kimball at that place reports that he finds nothing of special meteorological character that can be spoken of as important.—[C. A.]

THE THERMAL REGIONS OF THE GLOBE.[1]

By A. J. HERBERTSON, M. A., Ph. D., Professor of Geography, Oxford University.

In the paper on the thermal regions of the world, of which I propose to present an abstract, there are a number of sections about which I shall say nothing or next to nothing—e. g., the history of isothermal maps and the description of the different thermal regions. The reason for bringing the subject before this [Research] Department is to discuss the different methods in which the thermal conditions of the earth's surface can best be represented for the use of geographers, and the different attempts I have made to do this, which I wish criticized. In what follows I assume the temperature data are the most reliable available, and that the ordinary precautions have been taken in dealing with them.

If we start with the ordinary isothermal maps of the world, we have in Dr. Buchan's maps in the "*Challenger* Report" the one consistent set of maps which shows the distribution of temperature at sea level for every month of the year. There have been newer maps showing the mean annual temperature for July and January, but at the present time it would take many months to make maps more satisfactory than the *Challenger* ones for the different months of the year.[2]

The ordinary isothermal map contains many lines which, from the point of view of the study of the physics of the atmosphere, are desirable and essential; but for most geographical purposes it is necessary to choose from them those which have the greatest geographical significance. For simplicity's sake I have chosen to deal at present with the lines of 0°, 10°, and 20° C. (32°, 50°, and 68° F.). I have chosen 10° (50° F.) because that line roughly represents the average temperature for the month during which growth becomes active for most plants of economic importance in temperate regions. I have chosen the 20° (68° F.) [line] because it marks roughly on the world the boundary between regions where subtropical products can mature and those where they can not.

Taking those three isothermal lines it is possible from the ordinary isothermal map showing the mean annual temperature to make a map which shows temperature belts, but no map which merely shows the annual temperature is satisfactory. You are all familiar with the objections which are obvious on examining figure 1.[3] On the west coast in our latitudes the mean annual temperature is the mean of temperatures which differ very little from it, whereas on the east coast the same mean annual temperature is found in a region with very much colder winters and hotter summers; consequently, some seasonal isothermal line must be introduced in any maps which show the thermal zones.

In figure 2 is a reproduction [3] of Dr. Supan's map in which he combines mean annual isotherms and mean monthly isotherms taking the mean annual temperature of 20° C for the coldest month. I also have published maps showing the thermal zones, using the lines of 0°, 10°, 20° C., for the warmest and for the coldest month (fig. 3). This map is made by superposing the January and July isothermal maps showing the isotherms of 0°, 10°, 20° C. reduced to sea level.

[1] Abstract of a paper presented at a meeting of the Research Department, Dec. 14, 1911.
Reprinted from The Geographical Journal, London, November, 1912, **40**, p. 518-532.
[2] See Bartholomew's Atlas: Meteorology, Plate 3.—[C. A., jr.]
[3] This and other figures of the original published paper are not reproduced here. The maps referred to as "figure 1" and "figure 2" are to be found in Bartholomew's Physical Atlas: Meteorology, Plate 1, Inserts "Mean annual temperature" and "Temperature zones," respectively.—[C. A., jr.]

This is a very simple exercise, and anyone who has to teach geography knows how valuable it is to make pupils take a tracing of those three lines from a January isothermal map and a tracing of them from a July map, and then to make a thermal zone map by superimposing the two.

Some important facts illustrated by this map may be noted. There is a wide belt of ocean extending beyond the Tropics with an air temperature which never falls below 20° (68° F.). The belt narrows off the west coast of America, and widens off the east coast; it narrows off the west coast of Africa and widens again off the east coast of Africa. South and north of it are other belts which have summers with a temperature of over 20° C., but the winter's month is cooler than 20° C.

Two years ago I exhibited at the Research Department this and a number of other maps which had been constructed by similar graphic methods, to show mean seasonal temperatures, and from these seasonal maps a new one of the thermal zones. To obtain the seasonal isotherms, the three *Challenger* maps for December, January, and February were taken—the isothermal lines of 0°, 10°, and 20° C. were drawn, and the three maps superposed. The mean position of each isothermal line was determined, and a seasonal map for the northern winter and the southern summer produced. Similarly, the other three seasonal maps were obtained. From the four seasonal isothermal maps a new map was drawn, showing thermal zones which had certain merits which I do not propose to consider further in the present communication.

All these maps were based on isotherms reduced to sea level; but in all geographical work we find that the isotherms reduced to sea level are insufficient. We want a map of the actual air-temperature conditions, and not what they would be if the surface were at sea level. There are, however, many difficulties in the way of the construction of such maps. It is necessary to generalize the lines in order to obtain results which can be shown clearly on a small scale map. It must be remembered that in drawing all small scale maps it is necessary to make such generalizations, and that there is no particular reason why we should not attempt, in dealing with isothermal lines, the task which we always attempt in dealing with ordinary contour lines. Accordingly a good many years ago I took the isothermal maps for January and July, drew them on contoured maps, calculated the actual temperatures from them, and then drew the lines of 0°, 10°, and 20° C. as they run across the actual surface of the continents. The maps of figures 4 and 5 are reproductions of the maps after they have been revised by two pupils, Miss Rogers and Miss Taylor. Miss Taylor not merely revised the lines as they were shown on the earlier map, but first redrew the reduced isothermal lines for January and July, taking recent data into account.

In the ordinary map of isothermal lines reduced to sea level the line of 0° C. in January runs across the North American continent from the south of Vancouver Island to the south of the Great Lakes, but the parts of North America with a mean temperature in January under the freezing point extend much farther south—as far south in fact as the isothermal line of 10° C. in the map of isotherms reduced to sea level. In Asia the 0° C. isothermal line comes much farther south in Tibet than the line of 10° C. at sea level. This is a very important matter, especially in dealing with the distribution of temperature in Asia. It is of value not merely to the geographer, but also to the meteorologist, for it has an important effect on the distribution of pressure and winds. This difference between the two kinds of maps is perhaps even more noticeable in July. In Central Asia the region which has a mean temperature in July of over 20° C. is broken by the great mass of Tibet, and there is complete isolation between the high-temperature region of northern India and the high-temperature region of the Tarim Basin. The examination of no isothermal maps except those reduced to sea level and the forgetting of the height of Tibet, have given rise to some errors about monsoon winds current in ordinary textbooks. When the isothermal lines are not reduced to sea level, the low temperature of Tibet is very clearly shown and prevents any misconception about the action of Tibet on the Indian monsoon.

In the map of the thermal regions of the world (fig. 6) the lines of actual temperature drawn across the continents in the January map and those drawn across the continents in the July map have been superposed.

[In the map which was shown at the meeting the thermal regions of figure 6 were distinguished by means of colors, and it was pointed out that the colors of the map had been purposely chosen so that it was difficult to distinguish between the reds, and that for ordinary school use it was not important that the details indicated by tones of red should be noticed. For the higher classes of schools and for universities the careful examination of the differences of tones of various colors might profitably be undertaken.][4]

This is a map of thermal regions; and not merely of thermal zones. The land surface on the whole is cooler than the maps of thermal zones suggest. For instance, in the ever-hot belt in Africa of figure 3, we find not merely a contraction of the belt, especially south of the Equator, but an almost continuous north and south belt which runs along the East African plateau with a still cooler area over the Equator. The belt of hot summers and cold winters in figure 6 is very much smaller than in figure 3 in the Old World and is divided into a western region and an eastern region by a tongue of land with even colder winters and cooler summers which joins this belt of the North Temperate Zone to Tibet. This actual distribution of hot summers is of great economic importance, as for a number of plants the winter cold does not matter, especially if the plants are annual plants, and summer heat, not winter cold, determines their distribution.

It is not necessary to examine the details of this map more closely for the moment. While it has many advantages over the commoner thermal zone maps, it does not give all the information about temperature which it seemed to me might be expressed on a map of the world without undue complexity. Accordingly I set about making thermal maps which would show the number of months with temperature above 20°, above 10° C., and below the freezing point at each station.

The graphic method used for sea-level isotherms for the seasons was first employed, and these maps were shown here two years ago. This method could have been used for actual temperatures, if monthly maps of real temperatures had been available. It was, however, much simpler to adopt another method.

Standard temperature tables were taken—those in the "*Challenger* Report," in Dr. Hann's Klimatologie, in the official publications of the United Kingdom, United States, etc. From these tables other tables were com-

[4] This map, along with those of true January and July temperatures, is published on a sheet 60×40 inches by the Oxford University Press, price 8s. 6d. mounted on cloth.—[A. J. H.]

piled, giving the number of months that the temperature was over 20° C., over 10° C., and under 0° C., and the numbers were inserted on large-scale maps. The height of each station was noted on another set of maps. Such maps should be made on tracing paper to permit superposition. The line was now drawn separating regions where one month of the year at least had a mean temperature of 10° C. from those where no month had such a temperature and so on. In mountainous countries the valley or plateau conditions were considered, not those of the highest parts of the ranges. These lines are shown in the map of figure 7. The line between three and four months over 10° C. is rather important, as it indicates roughly the northern limit of profitable wheat growing, at any rate in the eastern half of North America.

Practically the whole of the intertropical land, with the exception of some of the higher parts of the Andes, have at least 10 months of the year over 10° C.—that is to say, as far as temperature is concerned, growth would be continuous in these regions, and the periods of growing and resting depend not on temperature but on rainfall.

A map showing the number of months over 20° C. and another showing the number of months under 0° C. have been prepared. From these three maps the map of figure 8 has been constructed. In this map, in the north, the dots indicate the region where no month in the year has a temperature of over 10° C., and that, you will notice, roughly coincides with the region of tundra. The areas with vertical broken lines are those in which at least one month in the year is over 10° C. In the southern part of this area at least three months in the year are over 10° C., but in winter at least six months in the year are under freezing point. Consequently the soil is frozen for over six months throughout this region, yet for at least three months in the south and one month in the north a temperature sufficient for active growth is found. The region with continuous vertical lines has at least four months over 10° C., and it has also four or five months of frost. As we pass from the heart of the continents toward the west the number of months over 10° C. does not alter, but the number of months with frost diminishes. In central Europe there are less than four months of frost, and in western Europe there is no month with a mean temperature under the freezing point. In the Far East, in the east of Korea and the extreme north of Japan, is a region which corresponds in this respect with central Europe, but there is nothing in the east of Asia which corresponds with the British Isles, France, and the Low Countries in Europe. In western North America, however, we find that milder region, as well as in the south of South America, in Tasmania, and in New Zealand.

In the next zone there is an area which still has from one to three frosty months, but here there are at least three months which have a temperature over 20°. That in North America is roughly the northern limit of maize cultivation. South of it comes a belt in which, though frost may occur, the mean temperature of the air is never under freezing point for one month. In this belt there are at least five and in the southern part of it there are six months of the year with a mean temperature of 20° C. In the next belt there are from seven to eight months of the year with a temperature of over 20° C., and in the last there are at least nine months of the year with the mean temperature over 20° C.

This map, perhaps better than any other, shows the very great area of the land surface which has a mean temperature of over 20° C., the most favorable area for plant growth, provided that the water supply is adequate.

In the Southern Hemisphere, of course, those belts are represented in the reverse order, and are most clearly shown in Australia and in South America. In Africa the height modifies the simplicity of the arrangement and we get exceptional areas which are distinctly more temperate than any other part of this belt in similar latitudes in the Southern Hemisphere, except in the Andes.

In the case of the west coasts of the continent we find the cool temperate conditions extending nearer the Equator than they do in the Northern Hemisphere, and going farther north on the western than on the eastern side. It is not, however, necessary for me to analyze the relationship between coastal temperatures, and prevailing winds and ocean currents. This is done in every textbook, and I am now more concerned with the discussion of methods than with the discussion in detail of the results.

There are difficulties in making a map of this kind for a region such as central Asia, where the variations of height are very great. In a mountain region we can not expect to show the actual surface temperature everywhere, as it varies from range to range in very short distances. It is convenient to block out the region over 4,000 meters, which is roughly everywhere a region of constant snow and ice, and then in the marginal region around to select the temperatures of the opener valleys rather than those of the summits as a guide to the shading or coloring which should be employed. The disadvantages of using the temperatures of the lower parts would be neutralized if some special shading were used to indicate a mountainous region. For we must have some convention to represent the condition of a complicated mountain region, and this, perhaps, is the best; but I should like to have the opinion of others on this point.

In addition to the maps, I have drawn a number of curves which show the seasonal distribution of temperature in these different thermal regions, and the gradual change in the range of temperature passing from west to east, the maximum range occurring within a comparatively short distance of the eastern margin of Asia, and occurring on the whole nearer the center of North America. The different types of configuration, the north-to-south mountain barrier in America, the west-to-east barrier in Asia, and the gradual rise of the greater part of northern Asia toward the east, have their effect in throwing the line of greatest range of temperature more toward the center in the case of North America, and more toward the east in Asia.

There is much work to be done in the more careful analysis of regions like British Columbia and the mountain belts of the United States, or of the Andes, or of central Asia, for which the temperature figures at present are insufficient. But that can only be undertaken later, and on much larger scales than this map of the world. For the purposes of the world map the detail I have shown is probably as much as can be used with clearness.

Those are the main points of the paper, which deals with two kinds of thermal region maps. One is made from the lines of warmest temperature and lowest temperature for the year; the other by counting the number of months above or under certain temperatures, plotting them, and drawing lines. The two maps show great resemblances, though they were made quite independently. One map brings out much more clearly the differences between the thermal value of the lands in the plains of North America and Asia than the other; this latter shows certain other points better. In making this new map Miss Evelyn Sandberg has aided me in super-

vising the whole of the tabulation done by Mr. H. N. Grant, and she plotted the figures on the maps, helped by Miss D. Forsaith in the case of North America.

DISCUSSION.

Capt. LYONS. * * * It is perfectly reasonable that the original data at the various points on the earth's surface should be treated from the special point of view of the geographer, and that from that point of view certainly the actual temperature on the earth's surface is of particular interest to him. * * * I can not say that I am attracted by some of those small and sharp *indentations in the curves*, especially in regions like central Africa and South America and elsewhere, seeing that we are dealing with such very generalized phenomena, and that the maps themselves are on a small scale. I question whether it would not be better to round off these lines somewhat more generally. As regards the question of *introducing the orographical detail* to some extent, I think technically it would be rather difficult to do so satisfactorily where there is already so much color detail on the maps, and in the end it might be preferable to work with a relief map alongside rather than try and include orographical data on the same one. In many cases the mountain range or the plateau is restricted in size, and to add such data from the cartographer's point of view may very easily produce some confusion. For the same reason I can not say that I am very much enamored of the proposal to use black for the high plateau and the highest mountain ranges.

Dr. D. T. MACDOUGAL. * * * I would join with the chairman in suggesting that these sharp deflections of the boundaries of the thermal zones should be avoided as much as possible. * * * We botanists are getting so that we are very much afraid to use average temperatures as a prime factor in determining the distribution of vegetation. To do so is impracticable, because the activity and distribution of vegetation does not depend on average daily, monthly, or annual temperatures. I can only say that our own work, so far as we have gone with it in dealing with the temperature factor and the activity of vegetation, is to use expressions indicating the hour-degrees of exposure above any chosen zero of activity. This radical departure from the temperature summation of averages, proposed a century ago, has been found applicable in determining the beginning of seasonal activity, and the limits of distribution of plants. The two ideas are as the average steam pressure in a boiler and the curve made by a recording gage. From another point of view, it is the maximum and minimum records that count rather than the averages, and vegetation is stopped or started by these extremes of temperature. Furthermore, the rate at which the temperature changes is also, I should say, a prime factor. To give a very common example, I presume everyone in the room is familiar with the starting of bulbs; that to get your bulbs started in the spring the temperature curve must rise rather suddenly. * * *

W. MARRIOTT. * * * Isothermal maps are certainly of extreme value to meteorologists, and I do not know how we would get on very well without having the readings reduced to sea level. Of course, that is the fundamental point in isothermal maps for meteorological purposes. The maps brought before us this evening are of great interest; they show rather the variability of the temperature in the various months, and that is of considerable importance. Of course we know that over the land surface the range of temperature is much greater than it is over the sea, but that is not the principle on which these maps have been compiled. The features, however, that have been brought out are likely to be very useful. Dr. Herbertson has done a great deal of work in the preparation of rainfall maps, and these temperature maps taken in conjunction with rainfall maps will be of great service in determining the climate suitable for the growth of crops in various parts of the world.

Capt. WILSON BARKER. My impression is that Dr. Herbertson's intention is to express meteorological conditions in a geographical manner. Meteorologists reduce all readings to sea level, but I am of opinion that it might be better to reduce them to the mean level of the earth's surface. * * *

Mr. J. FAIRGRIEVE. [Criticized the scale of the published wall chart.—EDITOR.]

Dr. HERBERTSON. * * * The difficulty in distinguishing between certain tints is intentional. * * * The colors were deliberately chosen so that the regions where differentiation was desirable stood out clearly in different colors and the tints of each color were used where differentiation was not so essential. I have used the maps constantly in teaching and have found that they have great advantages over the ordinary isothermal maps reduced to sea level. * * *

I do not mean to imply that these maps supersede the ordinary isothermal maps, even for geographers. Any one teaching geography scientifically must also use ordinary isothermal maps reduced to sea level. [My] real thermal maps are a necessary preliminary study in the investigation I am carrying on of the qualities of the different natural regions of the world. * * *

While bearing in mind the desirablity of selecting for this purpose temperatures which have some meaning for botanists, I do not pretend that those thermal maps, more particularly the early ones, are maps which can be used as a key to the distribution of vegetation. Maps of cumulative temperatures would have better results, but until the data exist the nearest approach to them that we can obtain for a map of the world on this scale is this map based on the duration of selected mean monthly temperatures. For certain parts of the world more may be possible, and I wish to make a thermal map of the British Isles to indicate not merely the number of months, but the number of days of certain average temperatures if the data are sufficient. Undoubtedly, as Dr. MacDougal said, it is necessary to take into account maximum and minimum temperatures and rates of change of temperature, as well as the mean temperature, in discussing the relations between temperature and vegetation.

I wish we could map wet-bulb temperatures, but wet-bulb temperatures are very difficult things to deal with. As far as I know there are very few long-period observations of wet-bulb temperatures which are worth anything. The wet-bulb temperatures made in the ordinary Stevenson screen are practically worthless. You must use some form of ventilated instrument whenever the air is almost still, and as yet the data for a reliable map are lacking. The question of the maximum and minimum temperature is a little less difficult, and Dr. van Bebber's maps[5] may profitably be used to supplement mine. Capt. Lyons says truly that on a map of this scale too much nicety in the curve is not desirable; but the irregularities in southeast Asia, for instance, are diagrammatic and indicate that there are alternations of warmer valley and colder mountain, and so far I think they are justifiable. * * *

[5] See Bartholomew's Atlas: Meteorology, Plate 2.—[C. A., Jr.]

SECTION III.—FORECASTS.

STORMS AND WARNINGS FOR MAY.

By EDWARD H. BOWIE, District Forecaster.

[Dated Washington, D. C., June 25, 1914.]

At the beginning of the month a high-pressure area of great magnitude covered the great central valleys and the lake region and dominated weather conditions over the entire country east of the Rocky Mountains, while a low-pressure area of pronounced character was over the Grand Banks and pressure was below normal over Saskatchewan and extreme western Texas. The high-pressure area passed slowly southeastward to West Virginia by the morning of the 3d, and at the end of the next 24 hours was off the Middle Atlantic coast. Frosts occurred on the morning of the 1st over the lower lake region, the Ohio Valley, and portions of the Middle Atlantic and New England States, and on the morning of the 2d over the lower lake region, lower Michigan, and the North Atlantic States, warnings of which were disseminated previously to the occurrence of the frosts.

The pressure-change map on the morning of the 2d showed a general fall throughout the Rocky Mountain region, and on the morning of the 3d a low center was over the Plains States. This area of falling pressure drifted eastward until on the morning of the 4th a storm of marked intensity was over extreme western Pennsylvania, whence it passed eastward to the southern New England coast by the morning of the 6th and to the mouth of the St. Lawrence by the following morning. General rains attended this disturbance from the Rocky Mountains eastward.

A disturbance that first appeared over Manitoba on the morning of the 5th passed slowly southeastward to Wisconsin by the morning of the 7th, with decreasing intensity. It thence moved southeastward to Ohio by the evening of the 7th, and recurving northeastward developed a secondary over Virginia on the morning of the 8th. The main center passed northeastward with decreasing intensity, while the Virginia center moved north-northeastward to northern New England with marked development by the morning of the 9th, and during the next 48 hours to Nova Scotia. Showers and thunderstorms were more or less general from the Mississippi Valley eastward.

A high-pressure area appeared on the North Pacific coast on the morning of the 4th, and on the following morning an offshoot from it was central over western Montana. On the evening of the latter date another high area was central over Alberta. The North Pacific high moved rapidly eastward with diminishing intensity and on the morning of the 7th was over West Virginia. The Alberta high passed slowly southeastward to the West Gulf and thence across the Gulf States to the Atlantic coast. On the morning of the 7th, frosts occurred in portions of Montana, Wyoming, and Nebraska, and on the 8th more or less generally over the Plains States, warnings being successfully issued in both cases.

Pressure became low over the North Pacific coast on the morning of the 7th, and on the following day pressure was low over the Plateau region and a low center had appeared over Alberta. On the 9th pressure was low from the northern Plains States southwestward to Utah. The northern center of this depression moved rapidly eastward with decreasing intensity, while a secondary was developing over the Rocky Mountain region. On the evening of the 10th the secondary was over Colorado, and by the following morning had moved to northeastern Kansas. It thence moved east-northeastward to the Middle Atlantic coast by the morning of the 13th, precipitation occurring quite generally over a belt immediately north of its path from the northern Rocky Mountain region eastward. On the 11th storm warnings were ordered for the Great Lakes and high winds occurred as indicated in the warnings. In connection with this same storm, storm warnings were ordered for the Atlantic coast from Delaware Breakwater to Eastport and winds of gale force occurred.

On the morning of the 10th a high-pressure area appeared over Saskatchewan, attended by temperatures near or below freezing, and on the following morning a center was over southern Saskatchewan. It passed slowly southward and then eastward to South Dakota by the morning of the 13th, on the evening of which date it was reinforced by another high area, the center of which appeared over Alberta. It passed thence slowly east-southeastward to western Pennsylvania by the 18th. On the 15th frosts occurred over the upper Mississippi Valley and Michigan and on the following morning in Michigan, the upper Ohio Valley and the Lower Lake region, warnings of which were in both cases previously disseminated. From western Pennsylvania the high settled slowly southward over the east Gulf States, where it maintained its identity until the 22d. On the morning of the 18th storm warnings were issued for the south Atlantic coast and high winds were reported over that region.

During the passage of this high eastward, conditions were unsettled over the Rocky Mountain region and showers occurred over the southern Rocky Mountain region, the southern plateau, and the west Gulf States.

A low center was over Alberta on the morning of the 17th and by the morning of the 24th it was over the Canadian Maritime Provinces, having passed at first slowly southeastward and later eastward over a northern route. Scattered showers and thunderstorms attended its passage over northern States from the Rocky Mountain region eastward to the Atlantic coast.

It was followed by a high area that first appeared over British Columbia on the morning of the 20th and which passed east-southeastward to the Middle Atlantic coast by the morning of the 24th.

This high was in turn followed by a low-pressure area that made its appearance over British Columbia on the evening of the 23d and followed a course along the northern boundary similar to the preceding low and attended by a more or less similar distribution of precipitation. Storm warnings were ordered for the Great Lakes except Superior on the 25th and high winds occurred as indicated.

This low was followed by another one of slight intensity that passed over practically the same course as the one referred to immediately above.

On the morning of the 26th the Pacific Ocean high had encroached on the north Pacific coast and there were indications of the formation of a secondary high center over the northern plateau region. This actually occurred, there being a separate center on the morning of the 27th over the northern Plains States, which later passed to Maine by the 29th and was off the coast by the following morning.

On the morning of the 27th a low appeared over Alberta and passing thence eastward was central over the Canadian Maritime Provinces on the last day of the month. This low caused some high winds in the region of the Upper Lakes.

It was followed by another north Pacific high that made its appearance on the evening of the 28th over northern Wyoming. On the last day of the month it was over Ohio.

At the end of the month a low-pressure area was over Quebec and pressure was low over the Rocky Mountain region and the Pacific coast, while pressure was relatively high over the Plains States and off the south Atlantic coast.

NORTHERN HEMISPHERE PRESSURE.

Alaska.—Pressure averaged above normal at all stations for the month. During the first two decades pressure was generally above the seasonal average while during the last decade it was generally below, except over the Aleutian Islands. Lows occurred about the 1st, 8th, 16th, 24th, 25th–26th, and 27th–28th; and highs about the 5th–6th, 12th, and 20th.

Honolulu.—Pressure averaged decidedly below normal, being continuously normal or below except on the first day of the month. Lows occurred on the 2d–3d, 10th, 16th, 18th, 20th–21st, 23d, 25th–26th, and 29th. There was no high of consequence during the month.

Iceland.—The pressure averaged slightly below normal for the month with rapid alternations of rising and falling pressure. Lows occurred on the 2d, 4th–5th, 6th–7th, 10th, 12th–13th, 15th–16th, 17th–18th, 21st–22d, and 29th; and highs on the 3d–4th, 8th–9th, 11th, 14th, 23d, and 26th.

Azores.—Pressure averaged decidedly above normal, being almost continuously above after the 3d. The lowest pressure of the month occurred on the 1st, and there was no low of consequence thereafter. Highs occurred on the 8th–11th, 19th, 24th, 28th, and last day of the month.

Siberia.—Pressure over this region averaged slightly above normal. Lows occurred about the 5th, 7th, 9th, 13th–14th, 15th, 23d, and 27th–28th; and highs about the 2d–3d, 11th–12th, 17th–18th, 20th, 26th, and 28th–29th.

SECTION IV.—RIVERS AND FLOODS.

RIVERS AND FLOODS, MAY, 1914.

By ALFRED J. HENRY,

Professor of Meteorology, in charge of River and Flood Division.

Destructive floods occurred in the first week of the month over a widely extended area in the Southwest from Kansas on the north to Texas in the south. The region of greatest flood intensity was along the South Fork of the Canadian, in Oklahoma. A second period of great flood frequency occurred on the 12th, 13th, and 14th in the smaller streams of southern Michigan and northwestern Ohio. The annual spring rise in both the Colorado and the Columbia was in progress in the lower reaches of those streams at the close of the month. The Colorado flood promises to be a rather full one, while that of the Columbia does not promise more than an ordinary flood.

According to press dispatches the loss of life in the southwestern floods aggregated 19 persons—3 in Kansas, 5 in Oklahoma and 11 in Texas. Property loss in the Oklahoma floods was large, especially in the matter of railway and county bridges; the loss due to bridges alone will aggregate close to half a million dollars.

The newly organized river service of Oklahoma, Section Director J. P. Slaughter in charge, was able to give timely notice of the coming of the floods in that State. Such notice was the more valuable by reason of the relative infrequency of floods in the rivers of that State and the further fact that the precipitation which caused it occurred on the headwaters of the Canadian in New Mexico and Colorado. No floods of equal magnitude have occurred since 1904. Some of the maximum stages are as follows:

MAXIMUM STAGES.

Canadian, Tex., 10 feet, 9:30 a. m., 2d.
Camargo, Okla., 11.5 feet, 11:30 p. m., 2d.
Bridgeport, Okla., 19 feet, noon, 3d.
Union City, Okla., 10.6 feet, midnight, 3d.
Purcell, Okla., 12–14 feet, about 2:30 a. m., 4th.
Tyrola, Okla., 22–24 feet, about noon, 4th.
Calvin, Okla., 18 feet (about), 3:30 p. m., 4th.
Eufaula, Okla., 16 feet, about 3 a. m., 5th.

The principal damage caused by this flood, outside of the destruction of bridges, was the loss of prospective crops in the bottom lands and damage to agricultural lands due to a deposit of sand which was left upon them in some localities.

A moderate flood occurred in the lower White River of Arkansas on the 8th. This flood was due to the combined effect of the floods in the Black and Upper White about 8 or 10 days earlier. Moderately high water also occurred in the Red River and its tributaries in Texas and Arkansas during the early days of the month. Flood stages were reached and passed as follows:

Fulton, Ark., 30.6 feet, May 3, flood stage 28 feet.
Finley, Tex., 28.1 feet, May 2, flood stage 24 feet.
Springband, Ark., 30.9 feet, May 10, 11, and 12, flood stage 29 feet.

The money loss to crops due to this flood is estimated at a little more than $100,000.

FLOOD IN THE ARKANSAS RIVER.[1]

Almost simultaneously with the severe floods in the Canadian, a flood of more than usual magnitude passed down the Arkansas during the first week in May. In that portion of the river between Dodge City, Kans., and the Kansas-Colorado line the river was out of its banks on the 2d and 3d. The crest of the flood at Dodge City, Kans., 6.7 feet, was reached at 9:30 p. m. of the 3d. This is 1.2 feet higher than previously recorded. The high water reached Wichita, Kans., on the 5th, cresting at 2.4 on the 6th, with a second crest of the same amount on the evening of the 7th. The amplitude of the flood wave at Dodge City was 7.1 feet; at Wichita, 6.5 feet—a remarkably small decay for the long stretch of river between Dodge City and Wichita. The property loss in the Arkansas Valley from the Colorado line to Wichita is estimated at $11,460, the bulk of which was occasioned by the river overflowing its banks and destroying prospective crops. Other lesser flood waves moved down the Arkansas in eastern Colorado during the last half of the month.

A trough-shaped depression, much like the one that caused the torrential rains of March 24–27, 1913, moved slowly eastward over northern Illinois, northern Indiana, and Ohio and northern Michigan on the 11th and 12th, passing over Pennsylvania and southern New York on the 13th. This disturbance gave continuous rainfall for about 24 hours during its eastward movement, and as a result caused a moderate flood in the Illinois River above Peoria. Owing to the slow progress of flood waves in this stream, the flood stage was not reached in the lower reaches of the river until the 24th and 25th.

The rivers of southeastern Michigan, including the Maumee of northwestern Ohio, overflowed their banks on the 12th, and the lowlands generally from Monroe, Mich., to Toledo, Ohio, were badly flooded. In the suburbs of Detroit much damage resulted from the failure of the sewers to carry off the water, the greatest individual sufferer being the Ford Motor Co., which was obliged to shut down its plant for three days. As the storm moved eastward the precipitation diminished, although it was sufficient to cause a moderate flood in the upper reaches of the Susquehanna.

FLOODS IN TEXAS RIVERS.

All streams of Texas from the Rio Grande to the Sabine were more or less flooded during May. The Trinity and Brazos were already out of banks during the latter part of April at Dallas and Waco, respectively, from heavy rains in April, with maximum stages of 37.8 feet at Dallas on April 29 and of 28.0 feet at Waco on April 28. The other

[1] See report of District Forecaster Brandenburg on Freshets in the Arkansas.

streams of the district were well up and rising. May was an exceptionally wet month; in fact, the total precipitation for the month exceeded that of the previously wettest month of record (June, 1899) by 0.61 inch. Heavy showers occurred at frequent intervals, now here, now there, causing large fluctuations in the volumes of water moving downstream, especially in the upper and central portions of the rivers. At some stations flood stages were attained two and three times during the month. The run-off was smaller than the amount of precipitation would indicate, and it is probable that drainage into the main channels was prevented or at least retarded by rank vegetation.

At the close of May the Trinity was falling in its lower reaches and rising again in its upper. The Brazos was falling in its upper reaches and rising in its lower. The Sabine and Neches were rising in their lower portions, and the Colorado, Guadalupe, and Rio Grande were falling.

While the streams were well out of banks, they were much below high-water mark, except the lower Trinity which attained a width of from four to six miles at Liberty with maximum stage at that place 0.2 foot higher than the previous high-water mark of June, 1908.

The rains and freshets caused considerable damage in all parts of the State, and farmers were greatly alarmed. Roads and fields were badly washed and water-soaked. Cultivation became impossible and crops were smothered by grass and weeds. Much corn and cotton was damaged and will require replanting. Train service was interrupted by washouts and softened roadbeds, county bridges were washed away, and much other damage was done. The losses from these freshets so far reported exceed $1,700,000, but in the aggregate will be much larger, as the returns are far from complete. The heaviest losers were the farmers in the Trinity, Brazos, Colorado, and Guadalupe valleys. Along the Trinity the losses reported aggregate $465,000; Brazos, $299,000; Colorado, $732,000; and Guadalupe, $126,000. A small per cent of the railroad and telephone companies reported a total loss of $94,000. The savings effected from warnings, so far as reported, aggregate $124,000. Live stock was driven from the danger zone upon receipt of the warnings and nearly all saved. Eleven persons were drowned in the swollen streams as a result of accident or foolhardiness.—*After B. Bunnemeyer, Section Director.*

The maximum stages were as follows:

Logansport on Sabine	Flood stage, 25.0 feet;	34.4 feet on 10th.
Rockland on Neches	Flood stage, 20.0 feet;	23.2 feet on 17th.
Liberty on Trinity	Flood stage, 25.0 feet;	28.3 feet on 22d.
Booth on Brazos	Flood stage, 39.0 feet;	42.0 feet on 13th.
Columbus on Colorado	Flood stage, 24.0 feet;	35.8 feet on 28th.
Gonzales on Guadalupe	Flood stage, 22.0 feet;	32.0 feet on 22d.
Mission on Rio Grande	? ?	23.3 feet on 29th.

Total loss by flood during May, 1914.

Texas rivers	$1,716,000
Oklahoma district:	
Bridges	500,000
Farms and crops (estimated)	377,000
Shreveport district:	
Crops	100,000
Stoppage of petroleum production	50,000
Detroit, vicinity of:	
Tangible property	50,000
Loss of wages and loss due to shut down of plant	1,815,000
Arkansas River (in Kansas):	
Bridges, buildings, etc	11,400
Crops	5,600
Arkansas River (in Colorado):	
Farms and farm property, including live stock and prospective crops	$25,675
Tangible property	54,715
Colorado River:	
Tangible property	50,000
Farms and farm property, including prospective crops	25,000
Gunnison River:	
Farms and farm property, including prospective crops	3,000
Grand total	4,783,390

FLOODS IN THE DENVER DISTRICT, MAY, 1914.

By FREDERICK H. BRANDENBURG, District Forecaster.

THE CANADIAN.

Heavy rains, torrential in localities, in northeastern New Mexico from April 29 to May 1, 1914, caused a severe flood in the Canadian River from its upper reaches to its junction with the Arkansas in Oklahoma. The upper drainage of the Canadian embraces the counties of Colfax, Mora, and parts of San Miguel, Guadalupe, Quay, and Union Counties; this region for the most part is mountainous, favorable to a large run-off which quickly filled the arroyos and creeks draining into the Canadian.

The greatest rainfall reported for the three days was 9.55 inches at Clayton, which lies close to the parting between the Canadian and the Cimarron, to the northward. The average for the three-day period for 42 stations in the area was 4.54 inches.

Apparently the rainfall was fully as great on the watershed of the Cimarron if one may judge from the record at Campo, Baca County, Colo. At this station the total for the three days was 7.20 inches.

The only river station in operation on the headwaters of the Canadian is located at Logan on the Chicago, Rock Island & El Paso Railroad, not far from the Texas border. During the first 24 hours after rain began the gage at Logan stood at 3 feet. After this the rise was rapid. On May 1 at 10 a. m. the river was at 18 feet; 11 a. m., 24 feet; 2:30 p. m., 29 feet; 3:15 p. m., 30 feet, the highest stage attained. By 5 p. m. it had fallen to 27 feet, and by 8 a. m. of the 2d the stage was 11 feet, and at 2 p. m., 8 feet. The maximum discharge has been estimated at 200,000 second-feet. The stages given are all from the gage on the railroad bridge, the gage upstream having been under water during most of the freshet. The highest attained, 30 feet, is 8 feet below the stage reached during the severe flood of September 30, 1904.

There was much damage due to flooding of lands adjacent to the river, and in localities not affected by the river overflow, but where the drainage facilities were unable to carry off the unusual run-off. Railroad companies, irrigation companies, farmers, the towns, and counties suffered monetary loss. The approximate value of the property damaged or destroyed, with loss due to suspension of business and wages of employees, is placed at $132,000.

At 11:30 a. m. of May 1 warnings were telegraphed to Tascosa, Tex., and railroad officials operating the Denver City & Fort Worth Railroad; also to the official in charge of the Weather Bureau office at Oklahoma City.

The table of precipitation below was furnished by the section director, Santa Fe, N. Mex.

Precipitation over northeastern New Mexico, April 29–May 3, 1914.

Station.	County.	April.		May.			Total.
		29	30	1	2	3	
							Inches.
Aurora	Colfax	1.14	1.20	0.88	0	0	3.22
Black Lake	do	(*)	1.70	0.93	0	0	2.63
Cimarron (near)	do	2.04	1.54	0.04	0	0	3.62
Dawson	do	0.28	1.18	1.56	0	0	3.02
Elizabethtown	do	0	1.10	0.80	0	0	1.90
Johnson's Park	do	0.04	1.70	2.10	0.18	0.01	4.03
Maxwell (near)	do	0	3.08	1.28	0	0	4.36
Miami	do	0.27	0	2.40	0	0	2.67
Raton	do	0.75	1.20	0.42	0.53	0	2.90
Springer	do	0.05	0.65	1.30	0	0	2.00
Taylor	do	0.11	0.53	1.33	0	0	1.97
Vermejo Park	do	0.05	2.00	0.73	0	0	2.78
Abbott	Mora	0.07	1.97	0.52	0	0	2.56
Chacon	do	(*)	2.11	0.75	0	0	3.06
Fort Union	do	0	0.40	0.97	0	0	1.37
Hoosier ranch	do	T.	6.08	2.25	0	0	8.33
Johnson's ranch	do	0.40	4.75	1.85	0	0	7.00
Mills (near)	do	0	3.00	1.90	0	0	4.90
Palo Verde	do	0.08	4.35	2.55	0	0	6.98
Pleasant View	do	0.40	5.48	3.05	0	0	8.93
Roy	do	0	5.00	2.40	0	0	7.40
Solano	do	T.	3.90	3.75	0	0	7.65
Wagon Mound (near)	do	0.05	0.58	1.25	0	0	1.88
Bell ranch	San Miguel	0	3.01	3.80	0	0	6.81
Cabeza	do	0	2.75	2.56	0	0	5.31
Campana	do	(*)	2.20	3.95	0	0	6.15
Rociada	do	0	1.83	0.64	0	0	2.47
Trementina	do	(*)	2.60	1.85	0	0	4.45
Cuervo	Guadalupe	0	2.00	2.50	0	0	4.50
Albert	Union	0.48	2.15	3.00	0	0	5.63
Clayton	do	(*)	6.20	3.35	0	0	9.55
Folsom	do	0.06	2.05	1.40	0	0	3.51
Hayden (near)	do	0.12	0.78	3.56	0.03	0	4.49
Pasamonte	do	1.57	4.15	0.64	0	0	6.36
Rosebud	do	1.10	3.54	0.10	0	0	4.74
Vance (near)	do	1.00	1.21	3.07	0	0	5.28
Kappus	Quay	0.55	1.80	1.30	0.20	0	3.85
Logan	do	0.05	2.00	3.63	0	0	5.68
Montoya	do	0	0.40	4.20	0	0	4.60
San Jon	do	0.33	0.85	1.18	T.	0	2.36
Tucumcari	do	(*)	1.60	0.33	0	0	1.93
Nara Visa	do	0.01	5.08	3.11	0	0	8.20

*Measurement included in next day.

THE ARKANSAS RIVER.

During May stages higher than usual occurred on a number of dates in the Arkansas River in Colorado. These high stages were in part due to temperature conditions favorable to uninterrupted melting of snow in the upper reaches during the latter part of April. But the principal cause of the prevalence of high water was the heavy rainfall, especially in the eastern part of Colorado. Several freshets occurred, but their duration was short and but little damage resulted, except from the freshet of May 1 and 2.

A tabulated statement of the rainfall on this watershed from April 29 to the end of May 3 is appended.

Daily precipitation, April 29 to May 3, inclusive, 1914, in watershed of the Arkansas in Colorado.

	Watershed.	April.		May.			Total.
		29	30	1	2	3	
							Inches.
Canon City	Arkansas	0.06	1.60	1.30	0.42	0.00	3.38
Colorado Springs	Fountain	1.35	2.03	0.54	0.00	0.07	3.99
Eads	Big Sandy	1.00	2.00	1.50	0.00	0.00	4.50
Florence	Arkansas	0.55	1.55	0.78	0.00	0.00	2.88
Fremont Experiment Station.	Fountain	0.42	0.91	0.71	0.21	0.00	2.25
Hamps	Big Sandy	0.30	1.75	0.77	0.03	0.02	2.87
Hoehne	Purgatoire	0.58	0.98	1.88	0.00	T.	3.44
Holly	Arkansas	0.52	1.62	0.96	0.00	0.00	3.10
La Junta	do	0.41	2.30	1.00	0.01	T.	3.72
Lake Moraine	Fountain	0.12	0.40	0.35	0.16	0.05	1.08
Lamar	Arkansas	0.18	0.77	3.30	0.00	0.00	4.25
La Veta Pass	do	0.00	0.98	0.00	0.00	T.	0.98
Limon	Big Sandy	0.25	1.48	0.70	0.00	T.	2.43
Madrid	Purgatoire	0.17	1.10	1.58	0.00	0.00	2.85
Maxey	Arkansas	1.00	2.00	4.10	0.00	0.00	7.10
Monument	Fountain	(*)	1.79	0.00	0.00	T.	1.79
North Lake	Purgatoire	0.06	2.76	0.90	0.00	0.12	3.84
Trinidad	do	0.35	0.91	1.70	T.	T.	2.96
Two Buttes Reservoir	Arkansas	0.20	1.05	2.79	0.00	.00	4.04
Yoder	do	0.16	1.61	0.42	0.04	0.06	2.29

*Measurement included in next day.

Flood of May 1 and 2.—The precipitation of April 30 and May 1 was excessive in many localities on the Arkansas watershed in the eastern part of the State. High stages occurred almost simultaneously on May 1 from Oxford Farmer's Dam, near Nepesta, eastward to the Kansas line. The flood subsided on May 3. East of La Junta the flooding of bottom lands resulted in much damage to farm lands, crops, live stock, bridges, and railroad property. The greatest damage occurred in the extreme eastern part of the State, where flood conditions were most pronounced. Timely warnings were issued for all high-water conditions.

On May 1, at 5 a. m., the river at Oxford Dam, near Nepesta, was 3.6 feet, or 0.4 below flood stage. At the same time the Purgatoire, a tributary joining the Arkansas above Fort Lyon, was rising rapidly. At 8 a. m. this river at Higbee was 8 feet, a rise of 6 feet in the preceding 24 hours. At the same time the Arkansas at Fort Lyon was 6.2 feet, or slightly above flood stage. At 8 a. m. the next day, May 2, the reading of this gage was 7 feet. Farther downstream the rise was more pronounced. At Amity Dam, near Prowers, on April 30, 1 foot of water was passing over the dam; in the evening of May 1 the depth of water passing over the dam was 5 feet, the maximum stage. By night of the 2d the river had fallen to 3 feet. The maximum discharge over the Amity Dam was estimated at 35,000 second-feet.

Flood in Fountain Creek in the vicinity of Pueblo, Colo., May 17–18.—During the night of May 17 a severe thunderstorm accompanied by heavy rainfall occurred in the vicinity of Fountain and Buttes, near the head of Fountain Creek, Colo. Flood conditions resulted in the area embraced by the Fountain watershed. Lowlands were flooded between Fountain and Pueblo, and the property loss was considerable. To the eastward of Pueblo only moderate river stages occurred in the Arkansas River from the Fountain freshet, and no material property damage resulted, except along the Fountain and in the vicinity of Pueblo. Traffic between Pueblo and Denver was suspended for the greater part of two days.

In connection with this flood warnings were issued for places to the east of Pueblo.

COLORADO RIVER, MAY, 1914.

In the upper reaches of the tributaries there were marked rises between the 8th and 12th; a steady flow was then maintained for the next seven days. High stages were general on the 24th and 25th, and practically the same heights were general again at the end of the month. In the San Juan the highest stage at Farmington, N. Mex., occurred on the 24th; in the Grand, at Fruita, on the 25th, and in the Green, at Elgin, Utah, on the 29th and 30th. At Topock, Ariz., near Needles, Cal., the maximum stage, 20.3 feet, occurred on the 31st, while at Yuma the maximum stage, 25.6 feet, occurred on the 29th and 30th.

MAY LAKE LEVELS.

By UNITED STATES LAKE SURVEY.

[Dated Detroit, Mich., June 2, 1914.]

The United States Lake Survey reports the stages of the Great Lakes for the month of May, 1914, as follows:

	Feet above mean sea level.
Superior	602.33
Michigan-Huron	580.32
Erie	572.91
Ontario	246.95

Lake Superior is 0.50 foot higher than last month, 0.26 foot higher than a year ago, 0.36 foot above the average stage of May of the last 10 years, 0.72 foot below the high stage of May, 1861, and 1.51 feet above the low stage of May, 1911. Average stages of the last 10 years indicate that the June level will be 0.3 foot higher.

Lakes Michigan-Huron are 0.26 foot higher than last month, 0.74 foot lower than a year ago, 0.46 foot below the average stage of May of the last 10 years, 3.20 feet below the high stage of May, 1886, and 0.76 foot above the low stage of May, 1896. Average stages of the last10 years indicate that the June level will be 0.3 foot higher.

Lake Erie is 0.81 foot higher than last month, 1.07 feet lower than a year ago, 0.06 foot above the average stage of May of the last 10 years, 1.51 feet below the high stage of May, 1862, 1.60 feet above the low stage of May, 1901. Average stages of the last 10 years indicate that the June level will be 0.2 foot higher.

Lake Ontario is 0.20 foot higher than last month, 1.02 feet lower than a year ago, 0.02 foot below the average stage of May of the last 10 years, 2 feet below the high stage of May, 1870, and 1.99 feet above the low stage of May, 1872. Average stages of the last 10 years indicate that the June level will be 0.2 foot higher.

SECTION V.—BIBLIOGRAPHY.

RECENT ADDITIONS TO THE WEATHER BUREAU LIBRARY.

C. FITZHUGH TALMAN, Junior Professor, in charge of Library.

The following have been selected from among the titles of books recently received as representing those most likely to be useful to Weather Bureau officials in their meteorological work and studies.

Ansel, E. A.
Beiträge zur Dynamik und Thermodynamik der Atmosphäre. Göttingen. [1913] 2 p. l., 67 p. 4 pl. 8°. (Inaug. diss.—Göttingen.)

Bosnia-Herzegovina. Landesregierung.
Ergebnisse der meteorologischen Beobachtungen an den Landesstationen, 1912. Sarajevo. 1913. xvi, 193 p. f°.

Brackett, F[rank] P[arkhurst].
The Smithsonian expedition to California for measurement of nocturnal radiation. (*In* Publication of the Astronomical society of Pomona college. Claremont, Cal. Oct. 1913. v. 3, p. 10–19. 4°.) [Joint investigations of Smithsonian institution and U. S. Weather bureau, including balloon observations.]

Cornish, Vaughan.
Waves of sand and snow, and the eddies which make them. London, *etc.* [1914.] 383 p. plates. 8°.

Chile. Instituto central meteorológico y geofísico.
Observaciones meteor. en la Isla de Pascua, Mayo 1911–Abril 1912, con estudios de F. Montessus de Ballore, F. Fuentes, W. Knoche. Meteorologische Beobachtungen auf der Osterinsel. [Spanish and German text.] Santiago de Chile. 1913. viii, 180 p. plates. f°.

Colombo observatory.
Report on the Colombo observatory, 1912, July to December, and the meteorology of Ceylon, 1912. [Colombo, 1913.] 11, G 47 p. plates. f°.

Dickinson, H[obert] C., & Mueller, E[ugene] F.
New calorimetric resistance thermometers. Washington. 1913. 483–492 p. front. 8°. (Reprint no. 200. From Bulletin of the Bur. of standards, vol. 9.)

France. Bureau central météorologique.
Annales, année 1911. II. Observations. Paris. 1913. v. p. f°.

Galli, Ignazio.
Effetti dei fulmini globulari sugli alberi e sulle erbe. Memoria quarta. Roma. 1913. 70 p. 4°. (*Estratto dalle* Memorie della Pontificia accademia Romana dei Nuovi Lincei, vol. 31.)

Garcia, Fabian, & Rigney, J. W.
Hardiness of fruit buds and flowers to frost. Las Cruces. 1914. 52 p. 8°. (New Mexico Agric. exper. station. Bulletin no. 89.)

Geography supply bureau.
Descriptive catalogue of lantern slides for meteorology and climatology. Also Dayton, O., flood: Lecture set of slides. Ithaca, N. Y. 24 p. 8°.

Ghent. Université.
Annuaire météorologique. Année météorologique, Mars 1913–Février 1914. Roulers. 1914. 94 p. 6 pl. 12°.

Greenwich. Royal observatory.
Results of the magnetical and meteorological observations, 1912. London. 1914. E xxxvi, E 74 p. f°.

Gruner, P[aul].
Dämmerungserscheinungen und Alpenglühen, beobachtet in Bern im Jahre 1913. 39 p. 8°. (*S.-A.* Mitteilungen der Naturforschenden Gesellschaft in Bern aus dem Jahre 1913.)

Guillaume, Ch.-Ed.
Le premier quart de siècle de la Tour Eiffel. Allocution prononcée a la fête du soleil, le 22 Juin 1912. Paris. 1913. 38 p. plate. 8°. [Describes the work of the meteorological observatory on the tower.]

Hankin, E[rnest] H[anbury].
Animal flight, a record of observation. London. [1913.] viii, 405 p. 8°. [Discusses meteorological conditions affecting bird flight, etc.]

Hellmann, G[ustav].
Regenkarten der Provinz Westfalen, sowie der Fürstentümer Waldeck, Schaumburg-Lippe, Lippe und des Kreises Grafschaft Schaumburg. 2. verm. Auflage. Berlin. 1914. 24 p. 2 pl. 4°. (Veröff. des K. preuss. meteorologischen Inst. Nr. 274.)
Über die Bewegung der Luft in den untersten Schichten der Atmosphäre. 1. Mitteilung. 415–437 p. 4°. (*S.-A.* Sitzber. der K. preuss. Akad. der Wissenschaften, 1914.)

Ille-&-Vilaine. Commission météorologique.
Bulletin annuel. Année 1912. Rennes. 1913. 26 p. 17 leaves. 6 pl. 4°.

Japan. Central meteorological observatory.
Annual report, 1912: Meteorological observations in Japan for the year 1912. Tokio. 1914. 1 p. l., 411 p. map. 4°.

Korselt, Ernst.
Über die täglichen regelmässigen Schwankungen des Barometers und ihren Zusammenhang mit dem Kreislaufe der Luft um den Erdball. Zittau. 1914. 16 p. 4°. (Beilage zum Jahresbericht 1914 des Kgl. Realgymnasiums Zittau. 1914, Progr.-Nr. 813.)

Leuschner, Armin O.
Twenty-five-year synopsis of the meteorological observations made at Berkeley from July 1, 1887, to June 30, 1912. Berkeley. 1914. 241–246 p. 4°. (University of California publications in geography, vol. 1, no. 5.)

Mauritius. Royal Alfred observatory.
Results of the magnetical and meteorological observations, 1909. Mauritius. 1913. v. p. 9 pl. 4°.

Müntz, [Charles] A[chille], & Lainé, E[dmond].
Eaux météoriques, sol et atmosphère. Paris. 1913. 2 p. l., 47 p. 4°. (Deuxième expédition antarctique française, 1908–1910. Sciences physiques: Documents scientifiques)

Quervain, Alfred de.
Quer durchs Grönlandeis. Die schweizerische Grönland-Expedition 1912/13. München. 1914. viii, 196 p. 15 pl. map. 8°. [Meteorological observations, chapter 12]

Rotmistrov, V. G.
The nature of drought according to the evidence of the Odessa experiment field. Translation from Russian. Odessa. 1913. 3 p. l., 48 p. plates. 8°. [M. of L. and A. Department of agriculture]

Rouch, J.
Electricité atmosphérique. Paris. 1913. 2 p. l., 39 p. 7 pl. 4°. (Deuxième expédition antarctique française, 1908–1910. Sciences physiques: Documents scientifiques)
Océanographie physique. Paris. 1913. 2 p. l., 46 p. 4°. (Deuxième expédition antarctique française, 1908–1910. Sciences physiques: Documents scientifiques)

Rykachev, M[ikhail] A[lexandrovich].
Rapport préliminaire de la Commission internationale polaire d'aérostation scientifique réunie à Copenhague le 28 février–1 mars 1914. St.-Pétersbourg. 1914. 369–376 p. map. 4°. (*Reprint:* Bulletin de l'Académie imp. des sci. de St.-Pétersbourg, 1914.

Schmauss, August.
Münchener aerologische Studien No. 6: H_e und T_e im Auf- und Abstiegsdiagramme. München. 1914. E6 p. f°. (*S.-A.* Beob. der meteor. Station im Königreich Bayern, Bd. 36, Jahrg. 1914)
Die Münchener Registrierballonfahrten im Jahre 1913. München. 1914. K 53 p. f°. (*S.-A.* Beob. der meteor. Stationen im Königreich Bayern, Bd. 35, Jahrg. 1913)

Smith, Albert.
Wind loads on buildings. (*In* Journal of the Western society of engineers. Chicago. April, 1914. v. 19, p. 369–392. 8°)

Spain. Observatorio central meteorológico.
Informaciones meteorológicas. [Radiogramas, etc.] [Madrid. 1914] 15, 4 p. plate. 8°.

Spang, Henry W.
Electrical and lightning engineering. A practical treatise explaining the electric destruction of underground water and gas pipes, electric wires, *etc.* Also explaining the principal causes of electric fires and the true state of the lightning science. New York. 1913. 77 p. 8°.

Spartel (Cape). Commercial signal station.
Annual report of the Secretary of Lloyd's . . . [1913]. [London. 1914.] 7 p. 4°. [Meteorology, p. 7]

Størmer, Carl.
Résultats des calculs numériques des trajectoires des corpuscules électriques dans le champ d'un aimant élémentaire. II. Faisceaux de trajectoires passant par un point; trajectoires spirales aux environs des trajectoires par l'origine. Kristiania. 1914. 2 p. l., 58 p. 8 pl. 4°. (Videnskapsselskapets skrifter. I. Mat.-naturv. Kl. 1913, no. 10)

Suzuki, Seitarô, & Soné, Také.
A wind-cave at Watarasé, Japan. (*In* Science reports of the Tôhoku imp. univ. Sendai, Japan. April, 1914. 1st ser., v. 3, no. 3, p. 101–111 p., 3 pl. 4°)

Switzerland. Meteorologische Zentral-Anstalt.
Annalen, 1912. 49. Jahrgang. Zürich. n. d. v. p. plates. f°.

Tananarivo. Observatoire de Madagascar.
Observations météorologiques, 24e volume, 1912. Tananarive. 1913. vi, 272 p. 8°.

Tsukubasan. [Observatorium].
Ergebnisse der meteorologischen Beobachtungen im Jahre 1911, herausgegeben von dem Meteorologischen Zentral-Observatorium. Tokio. 1914. 2 p. l., 129 p. f°.

Venezuela. Direccion general de estadistica.
Annuario estadistico. (Year book of Venezuela.) 1910. Containing documents for 1911 and 1912. [Text in Spanish, French, and English] Caracas. 1913. xxi, 504 p. plates. 4°. [Climatology, 1910, p. 2–5; 1905–1910, p. 387–394]

Wright, M. E. S.
A medley of weather lore. Bournemouth. 1913. 144 p. 16°.

Zi-ka-wei, *China*. Observatoire.
Observations magnétiques faites à l'Observatoire de Lu-kia-pang. Tome II, année 1909. Zi-ka-wei-Chang-hai. 1914. 2 p. l., 90 p. plates. f°.

RECENT PAPERS BEARING ON METEOROLOGY.

C. FITZHUGH TALMAN, Junior Professor, in charge of Library.

The subjoined titles have been selected from the contents of the periodicals and serials recently received in the Library of the Weather Bureau. The titles selected are of papers and other communications bearing on meteorology and cognate branches of science. This is not a complete index of the meteorological contents of all the journals from which it has been compiled. It shows only the articles that appear to the compiler likely to be of particular interest in connection with the work of the Weather Bureau.

Astrophysical journal. Chicago. v. 39. May, 1914.
Ångström, A. K., & Kennard, E. H. Some pyrheliometric observations on Mount Whitney. p. 350–360.

Engineering news. New York. v. 71. June 18, 1914.
Branch, L. V. Records of heavy rainfall and run-off in Porto Rico. p. 1358–1359.

Franklin institute. Journal. Philadelphia. v. 177. June, 1914.
Abbot, C[harles] G[reeley]. The radiation of the sun. p. 641–664.

Indian meteorological department. Memoirs. Calcutta. v. 21. pt. 8. 1914.
Walker, Gilbert T. A further study of relationships with Indian monsoon rainfall. p. 1–12.

Nature. London. v. 93. May 28, 1914.
Dines, W[illiam] H[enry]. Temperature-difference between the up and down traces of sounding-balloon diagrams. p. 320–321.
[Cave, Charles J. P.] Upper air research. p. 334–338. [Extr. Q. J. Roy. Met. Soc.]

Royal meteorological society. Quarterly journal. London. v. 40. April, 1914.
Cave, Charles J. P. Upper air research. p. 97–109.
Shaw, W[illiam] N[apier]. The interpretation of the results of soundings with pilot balloons. p. 111–122.
Dobson, G. M. B. Pilot balloon ascents at the central flying school, Upavon, during the year 1913. p. 123–135.
Mossman, R[obert] C. Meteorology of the Weddell quadrant during 1912. p. 137–153.
Bjerknes, V[ilhelm]. Terminology in dynamic meteorology. p. 160–162.
Whipple, F. J. W. Some units for dynamical meteorology. p. 162–163.
Dr. J. H. Tripe. p. 169. [Obituary.]
M. W. Zambra. p. 169. [Obituary.]

Royal Society. Proceedings. London. ser. A. v. 90. 1914.
Pring, J. N. The occurrence of ozone in the upper atmosphere. p. 204–219. (A. 617.)
Rudge, W. A. Douglas. On the electrification produced during the raising of a cloud of dust. p. 256–272. (A 618.) [Author suggests explanation of electrical phenomena of dust storms and volcanic eruptions. p. 260.]
Larmor, Joseph, & Larmor, J. S. B. On protection from lightning and the range of protection afforded by lightning rods. p. 312–318. (A. 618.)

Royal society of South Africa. Transactions. Cape Town. v. 4. pt. 1. 1914.
Rudge, W. A. Douglas. On the daily range of the atmospheric potential gradient at Bloemfontein, and the influence of dust storms. p. 75–87.

Scottish geographical magazine. Edinburgh. v. 30. June, 1914.
Penck, Albrecht. The shifting of the climatic belt. p. 281–293.

Terrestrial magnetism and atmospheric electricity. Baltimore. v. 19. June, 1914.
Swann, W. F. G. The theory of electrical dispersion into the free atmosphere, with a discussion of the theory of the Gerdien conductivity apparatus, and of the theory of a collection of radioactive deposit by a charged conductor. p. 81–92.
Wigand, Albert. Measurements of the electrical conductivity in the free atmosphere up to 9,000 meters in height. p. 93–101.

U. S. Bureau of Standards. Bulletin. Washington. v. 10. 1914.
Waidner, C. W., & others. Observations on ocean temperatures in the vicinity of icebergs and in other parts of the ocean. p. 267–278. (Feb. 20.)
Stillman, M. H. Note on the setting of a mercury surface to a required height. p. 371–374. (Apr. 15.)

Yearbook of wireless telegraphy and telephony. London. 1914.
Erskine-Murray, J. The function of the atmosphere in transmission. p. 504–513.
Lempfert, R. G. K. The application of wireless telegraphy to meteorology. p. 539–549.
International time and weather signals. p. 557–569.
Eccles, W. Radio-telegraphic investigations. Work of the British Association committee. p. 570–587. [Describes investigations of "strays." See above, p. 245.]

Académie des sciences. Comptes rendus. Paris. t. 158. 1914.
Esclangon, Ernest. Sur un enregistreur de l'intensité des chutes de pluie. p. 1467–1470. (18 mai.)
Guilbert, Gabriel. Sur la prévision du temps. p. 1470–1472. (18 mai.)
Baldit, Albert. Sur un éclair en boule. p. 1542–1543. (25 mai.)
Boutaric, A. Influence de la polarisation de la lumière diffusée par le ciel sur les valeurs obtenues pour la constante solaire. p. 1600–1602. (2 juin.)

Annales de géographie. Paris. 23 année. 15 mai 1914.
Anfossi, G[iovanni]. La pluie en Piémont et dans les Alpes occidentales. p. 271–275.

Nature. Paris. 42 année. 6 juin 1914.
Dubreton, J. L'électricité atmosphérique et les paratonnerres. p. 20–21.

Société météorologique de France. Annuaire. Paris. 62 année. avril 1914.
Maillet, Edmond. Sur les conditions de la prise par les glaces ed la Seine à Paris. p. 97–98.

Annalen der Hydrographie und maritimen Meteorologie. Berlin. 42. Jahrgang. Heft 6. 1914.
Köppen, W[ladimir]. Über Böen, insbesondere die Böe vom 9. September 1913. p. 303–320.

Himmel und Erde. Berlin. Jahrgang 26. Mai 1914.
Burk, Karl. Das Eis der Pole. p. 337–348.

Meteorologische Zeitschrift. Braunschweig. Band 31. Mai 1914.
Wallén, Axel. Temperatur, Niederschlags- und Wasserstandsschwankungen in Nordeuropa. p. 209–220.
Hesselberg, Th. Die Reibung in der Atmosphäre. p. 220–232.
Heim, Fritz. Diamantstaub und Schneekristalle in der Antarktis (Wedellsee). p. 232–235.
Kesselitz, W[ilh] v. Über die Windverhältnisse in der Adria. p. 248–251.

Naturwissenschaften. Berlin. 2. Jahrgang. 22. Mai 1914.
Kähler, Karl. Die durchdringende Strahlung der Atmosphäre. p. 501–505.

Wiener Luftschiffer-Zeitung. Wien. 13. Jahrgang. 15. Mai 1914.
Wilfred de Fonvielle. p. 108–111. [With two portraits.]

Zeitschrift für Balneologie. Berlin. 6. Jahrgang. 15. April 1914.
Zur Errichtung des physikalisch-meteorologischen Observatoriums in Oberhof. p. 54.

Hemel en Dampkring. Den Haag. 12. Jaargang. Mei 1914.
Canniegieter, H. G. Problemen der aerologie. p. 1–10.

Società degli spettroscopisti italiani. Memorie. Catania. ser. 2. Aprile 1914.
Platania, Giovanni. Il pulviscolo vulcanico dell' alta atmosfera e la radiazione solare. p. 62–72.

NOTES FROM THE WEATHER BUREAU LIBRARY.

By C. FITZHUGH TALMAN, Junior Professor, in charge of Library.

METEOROLOGY IN RECENT REFERENCE WORKS.

The eleventh edition of the Encyclopædia Britannica, published in 1910–11, in addition to the long memoirs on "Meteorology" and on "Climate and climatology," contains articles (or parts of articles) on the following meteorological topics:

Aeronautics (Scientific ascents).
Afterglow.
Anemometer.
Anthelion.
Anticyclone.
Atmosphere.
Atmospheric electricity (C. Chree).
Aurora polaris.
Barometer.
Beaufort scale.
Blizzard.
Bora.
Breeze.
Brickfielder.
Brocken, Spectre of the.
Buys Ballot's Law.
Chinook.
Climate and climatology (R. DeC. Ward).
Climate of the United States (W. M. Davis).
Cloud (A. W. Clayden).
Cloud.
Cloudburst.
Cyclone.
Dawn.
Dew (W. N. Shaw).
Doldrums.
Dust.
Earth currents (C. Chree).
England, Climate (H. R. Mill).
Etesian wind.
Euroclydon.
Ferrel's law.
FitzRoy, Robert (J. K. Laughton).
Fog.
Föhn.
Frost.
Hail.
Halo.
Harmattan.
Helm wind.
Horse latitudes.
Hurricane.
Hygrometer.
Isabnormal (or Isanomalous) lines.
Isobar.
Isotherm.
Khamsin.
Kite flying, meteorological use (W. H. Dines).
Leste.
Leveche.
Lightning.
Lightning conductors (K. Hedges).
Maestro.
Meteorology of Europe (G. G. Chisholm).
Mirage.
Mistral.
Monsoon.
Norther.
Pacific Ocean, meteorology and temperature (H. N. Dickson).
Pampero.
Polar regions, Antarctic climate.
Polar regions, Arctic climate (H. R. Mill).
Rain.
Rainbow.
Roaring forties.
St. Elmo's fire.
Simoom.
Sirocco.
Sleet.
Snow.
Snow-line.
Squall (W. N. Shaw).
Storm.
Sunshine (W. N. Shaw).
Surge.
Symons, George James.
Terrestrial magnetism (C. Chree).
Thermometry.
Thunder.
Timber-line.
Twilight.
Tornado.
Trade winds.
Typhoon.
V-shaped depression.
Waterspout.
Weather.
Wedge.
Wind.

In contrast to the imposing aggregate of information represented by the foregoing list, it may be noted that the Britannica contains no detailed description of a *thunderstorm* or of the various forms of *lightning;* no account of *ignis fatuus;* no biographies of Ferrel, Buys Ballot, Dove, Hann, Hellmann, Shaw, Angot, Bezold, Rotch, L. Teisserenc de Bort, A. Buchan, Luke Howard, Mohn, Sprung, Loomis, and a host of other eminent meteorologists, living and dead; no article nor even an index-entry on *phenology* (!); besides which there are numerous other omissions that seem serious to the meteorologist, though the public at large doubtless regards them more indulgently.

The New International Encyclopædia, second edition, of which two volumes (A–Baza) have thus far appeared, numbers among its contributors the Chief of the Weather Bureau and two other officials of this bureau. Apparently the editors of this work have planned to devote an unusual amount of space to contemporary biography, and meteorologists will be well represented, though in the portion already published we miss the names of John Aitken, Algué, and Assmann.

The three great American dictionaries of the English language that have recently appeared in new editions—the Century, the New International, and the Standard—present a much larger fraction of the total vocabulary of meteorology than ever before secured the recognition of lexicographers, though hundreds of meteorological terms still await definition in general or special dictionaries. It may be noted that a few meteorological definitions in the Century Dictionary Supplement, published in 1909, contained typographical errors, which have been corrected in the new edition, published in 1911. A number of errors of the same character appear in the Standard, but these will doubtless be corrected in new impressions of the work.

The Handwörterbuch der Naturwissenschaften (Jena, 1912), of which nine bulky quarto volumes have appeared, carrying the work through *Tra-*, contains several noteworthy articles on meteorological subjects, though some of its omissions are rather striking. The late Dr. R. Börnstein contributes the general memoir on meteorology, which one seeks in vain under "Meteorologie," but finds under "Atmosphäre." There are no articles on "Klima," "Klimatologie," or "Klimatographie." "Atmosphärische Elektrizität" and "Atmosphärische Optik" are authoritatively discussed by H. Gerdien and F. M. Exner, respectively. "Barometer" is contributed by A. Wegener. Lightning and its effects and lightning protection are discussed by Walter, Wegener, and Spies. A long memoir on "Eis," by H. Hess, is chiefly devoted to glaciers. "Luftdruck" receives extensive treatment by Wegener. "Paläoklimatologie" is discussed by M. Semper. "Polarlicht," is treated by G. Angenheister. Aside from several brief biographies of meteorologists, the foregoing are all the meteorological articles in the first nine volumes. The list seems extremely fragmentary, though doubtless the index which is ultimately to be published will reveal the whereabouts of information on many other meteorological topics.

SECTION VI.—WEATHER AND DATA FOR THE MONTH.

THE WEATHER OF THE MONTH.

By P. C. DAY, Climatologist and Chief of Division.

Pressure.—The distribution of the mean atmospheric pressure over the United States and Canada and the prevailing directions of the winds are graphically shown on chart VII, while the average values for the month at the several stations, with the departures from the normal, are shown in Tables I and III.

For the month as a whole, barometric pressure was above the normal over practically the entire country, as in the preceding month, only limited areas near the central and northern Pacific coast showing values near or slightly below the normal. The positive departures were quite marked and uniform over all districts east of the Rocky Mountains, being somewhat more pronounced, however, in the central and southern sections.

At the beginning of the month an extensive area of moderately high pressure overspread all districts from the Rocky Mountains eastward, but this gave way about the 3d to relatively low pressure and unsettled conditions, which continued over the more eastern districts till about the 8th. From the 8th to the 12th pressure was again high over the central and southern States, with lower barometer readings to the northward, and from the 14th to the 24th rather marked high pressure again obtained over practically all eastern sections of the country. From the last-named date to the 28th a storm area passed eastward over the northern tier of States and the southern Canadian provinces, and at the same time low pressure prevailed over the Plateau and Rocky Mountain regions. The month closed with relatively low pressure over the more northern districts and with high pressure to the southward.

The distribution of the highs and lows for the month was favorable for the occurrence of southerly winds as the prevailing direction over the great central valleys and the Plains region, and of northerly or northwesterly winds over the Middle and North Atlantic States, while the prevailing directions were variable in the South Atlantic States and from the Rocky Mountain region westward to the Pacific coast.

Temperature.—The cool weather over the northern districts during the latter part of April, referred to in the last report, gave way to warmer weather about the beginning of the present month, and after the first few days warm weather prevailed over all central and eastern sections, but cool weather obtained in the far Northwest during the first week, the minimum temperature falling below freezing at many points in that region and to near 20° in parts of Wyoming and to the northward. This cool area advanced to the central valleys and thence to the Gulf States by the 9th, but with diminished tendency to low temperatures, except over the more northern districts, where it continued cold, with some frost. Following the cold area warmer weather overspread the districts between the Rocky Mountains and the Mississippi River, and by the 10th temperatures had risen to normal or above over practically all parts of the country, save along the northern border from the Great Lakes westward.

About the 11th unseasonably cold weather advanced from the Canadian Northwest, with minimum temperatures below freezing and with frosts at many points in the northern Plains and Mountain districts. During the next few days the cold area overspread the central valleys and eastern States, and by the 15th or 16th frost had extended into the Lake region, northern New York, and the interior of New England. Following this cool spell there was a tendency to warmer weather over most districts, and by the 26th warm weather was general over all sections from the Plains region eastward, but some sharp falls in temperature had occurred in the Rocky Mountain and Plateau regions, with frost reported from exposed points. During the next few days the cool area moved over the more northern districts to New England, but the weather continued warm over the southeast, the maximum temperatures over much of the east Gulf States, and on the 29th equaling or slightly exceeding any previous records for the last decade of May, and reaching 100° at points in Georgia.

The mean temperature for the month as a whole was above the normal in all districts, save in Texas and Oklahoma and portions of the adjoining States and in southern California. The greatest plus departures occurred in the central and northern Plateau districts, the west Lake region, and along the Atlantic coast from Virginia northward to southern New England. Over the greater part of the country the departures, however, were not marked, the monthly mean temperatures being near the normal.

Precipitation.—The month opened with unsettled, rainy conditions in the Southwest, including the central portions of the Rocky Mountain and Plateau regions. During the first week the rain area extended eastward and northeastward to the Atlantic coast, and by the end rain had occurred over practically all eastern districts, with some snow in the more northern portions. The precipitation was heavy in portions of the central Rocky Mountain and Plains regions and the West Gulf States.

From the 10th to the 13th a storm area moved from the central mountain districts eastward to the Atlantic coast, accompanied by some heavy rains in portions of the upper Mississippi Valley and the Lake region, and by the latter date some heavy falls had again occurred in Texas. From the middle of the month till about the 25th generally fair weather obtained over practically all eastern districts, which were under the influence of high barometric pressure, but showers were frequent in the Southwest and in portions of the Plains States and upper Mississippi Valley, with some further heavy falls in those districts. From the 25th to the end of the month unsettled showery conditions prevailed over most eastern sections, save in the east Gulf and Middle and South Atlantic States, and portions of the Ohio and middle Mississippi Valleys, with some still further heavy falls in the Plains States, including Texas, the upper Mississippi Valley, and the Lake region.

The precipitation for the month as a whole was heavy in most of Texas, where the monthly amounts ranged from 6 to 10 inches, and also in Oklahoma, western Kansas, and the eastern portions of Colorado and New Mexico, where they ranged from 4 to 6 inches or above. The amounts were also generous, ranging from 4 to 6 inches or more in the Lake region and the upper Mississippi and Missouri Valleys, while amounts ranging from 2 to 4 inches were received over practically all portions of the Plains region not previously mentioned. From 1 to 2 inches occurred in much of the Rocky Mountain and Plateau regions, but in the central and southern portions of the plateau and thence westward to the Pacific coast the amounts were quite generally less than 1 inch, but along the north Pacific coast they were slightly in excess of 2 inches. In the Atlantic coast districts, the central and east Gulf States, most of the Ohio and portions of the middle Mississippi Valleys the precipitation for the month was markedly deficient, less than 1 inch occurring over large portions of these districts, resulting in severe drought.

GENERAL SUMMARY.

The weather of the month was characterized by the sustained absence of rainfall with severe droughty conditions in the Southeastern States and portions of the Ohio and middle Mississippi valleys, and the excessive moisture received in the Southwest, especially Texas and Oklahoma. The month developed one of the severest spring droughts ever known in portions of the South Atlantic and East Gulf States, and other large areas of the droughty region suffered severely from lack of sufficient moisture, resulting in the delaying of farming operations and poor germination of such crops as could be planted. On the other hand, the excessive moisture in Texas and Oklahoma delayed field work and prevented proper cultivation of the soil.

In the principal corn and winter wheat growing States conditions were favorable in the States to westward of the Mississippi River and over the northern portions of the belt to the eastward, but dry weather prevailed in the southern portion of the eastern belt. In the spring-wheat region the weather was generally favorable and all vegetation made rapid growth.

Over the mountain and plateau districts of the West the weather was generally favorable and vegetation made satisfactory growth, but by the close of the month some dry-farming districts were needing rain. In the Pacific coast States the weather was favorable for all farming operations.

Average accumulated departures for May, 1914.

Districts.	Temperature.			Precipitation.			Cloudiness.		Relative humidity.	
	General mean for the current month.	Departure for the current month.	Accumulated departure since Jan. 1.	General mean for the current month.	Departure for the current month.	Accumulated departure since Jan. 1.	General mean for the current month.	Departure from the normal.	General mean for the current month.	Departure from the normal.
	° F.	° F.	° F.	Inches	Inches	Inches			P. ct.	P. ct.
New England	56.6	+2.0	− 5.9	2.08	−1.30	−1.10	5.1	−0.4	71	− 7
Middle Atlantic	64.4	+2.9	− 1.9	2.00	−1.50	−1.80	4.1	−0.9	61	−11
South Atlantic	71.1	+1.3	− 0.4	0.75	−3.00	−6.10	3.6	−0.9	64	−10
Florida Peninsula	77.9	+0.2	− 4.2	2.09	−2.20	−2.10	5.8	+1.4	76	0
East Gulf	72.9	+0.6	− 2.7	0.69	−2.80	−4.40	4.3	−0.4	62	− 9
West Gulf	72.0	−0.9	− 1.2	5.53	−1.40	−2.40	6.2	−1.4	78	+ 3
Ohio Valley and Tennessee	66.2	+1.1	− 2.5	1.74	−1.90	−5.00	4.1	−0.9	61	− 7
Lower Lakes	59.2	+1.7	− 5.3	3.62	+0.50	+1.50	4.3	−1.1	67	− 4
Upper Lakes	56.3	+3.7	+ 1.4	3.28	−0.20	−0.50	4.5	−1.0	68	− 4
North Dakota	55.6	+1.4	+11.1	1.92	−0.60	−1.30	4.2	−1.3	64	+ 2
Upper Mississippi Valley	64.3	+2.3	+ 6.8	2.68	−1.50	−3.50	4.4	−0.9	63	− 5
Missouri Valley	63.1	+1.1	+10.7	3.03	−1.20	−2.30	5.1	0.0	65	0
Northern slope	54.0	+1.0	+14.0	1.42	−0.70	−1.50	5.1	−0.4	62	+ 4
Middle slope	62.6	−0.2	+ 9.5	3.60	−0.20	−1.20	5.6	+0.7	68	+ 7
Southern slope	68.7	−2.0	+ 5.3	6.16	+3.30	+1.40	5.8	+1.4	70	+ 9
Southern Plateau	65.6	−0.4	+ 4.7	0.77	+0.50	−0.10	3.2	+0.5	42	+10
Middle Plateau	59.1	+2.9	+11.0	0.69	−0.50	−0.10	4.4	+0.3	46	0
Northern Plateau	59.4	+2.5	+17.7	0.91	−0.80	−1.20	4.5	+0.6	53	− 3
North Pacific	55.7	+2.5	+14.5	1.17	−1.40	+0.20	4.9	−1.4	74	− 2
Middle Pacific	58.3	+0.7	+10.1	0.50	−0.80	−0.80	4.6	+0.6	72	+ 1
South Pacific	61.8	+0.2	+14.8	0.14	−0.40	+3.80	5.2	+1.1	72	+ 3

Maximum wind velocities, May, 1914.

Stations.	Date.	Velocity.	Direction.	Stations.	Date.	Velocity.	Direction.
		mis./hr.				mis./hr.	
Buffalo, N. Y.	26	54	sw.	New York, N. Y.	27	90	nw.
Do.	27	58	sw.	Pittsburgh, Pa.	11	68	nw.
Corpus Christi, Tex.	3	52	e.	Do.	12	57	nw.
Duluth, Minn.	25	56	sw.	Do.	27	57	w.
El Paso, Tex.	29	60	e.	Point Reyes Light, Cal.	27	65	nw.
Hatteras, N. C.	5	55	w.	Savannah, Ga.	7	70	w.
Houghton, Mich.	25	50	nw.	Sioux City, Iowa.	23	51	w.
Louisville, Ky.	7	60	w.	Syracuse, N. Y.	27	54	sw.
Mt. Weather, Va.	5	52	nw.	Valentine, Nebr.	25	52	sw.
New York, N. Y.	1	50	nw.				
Do.	23	51	nw.				

CONDENSED CLIMATOLOGICAL SUMMARY.

In the following table are given for the various sections of the climatological service of the Weather Bureau the monthly average temperature and total rainfall; the stations reporting the highest and lowest temperatures with dates of occurrence; the stations reporting the greatest and least total precipitation; and other data, as indicated by the several headings.

The mean temperature for each section, the highest and lowest temperatures, the average precipitation, and the greatest and least monthly amounts are found by using all trustworthy records available.

The mean departures from normal temperatures and precipitation are based only on records from stations that have 10 or more years of observations. Of course the number of such records is smaller than the total number of stations.

Summary of temperature and precipitation, by sections, May, 1914.

Section.	Temperature (°F.).								Precipitation (inches and hundredths).					
	Section average.	Departure from the normal.	Monthly extremes.						Section average.	Departure from the normal.	Greatest monthly.		Least monthly.	
			Station.	Highest.	Date.	Station.	Lowest.	Date.			Station.	Amount.	Station.	Amount.
Alabama	71.8	+0.4	Wetumpka	104	30	2 stations	42	9	1.05	−2.99	Cordova	3.30	Daphne	T.
Arizona	67.6	+1.7	Maricopa	110	21	Alpine	18	1	0.32	+0.05	St. Johns	2.15	7 stations	0.00
Arkansas	69.5	+0.3	2 stations	97	26†	Dutton	34	9	3.34	−2.16	Wiggs	6.92	Corning	1.02
California	62.3	+0.2	Greenland Ranch	116	29	Tamarack	20	9†	0.69	−0.53	Kennett	4.66	31 stations	0.00
Colorado	53.1	+1.1	Wray	96	26	Fraser	3	1	2.51	+0.70	Campo	13.77	Woodmen Sanatorium.	0.10
Florida	75.8	+0.3	Mount Pleasant	104	31	2 stations	45	9†	1.74	−2.09	Homestead	6.65	3 stations	0.00
Georgia	72.7	+0.9	Waynesboro	104	29	Blue Ridge	36	10	0.74	−2.73	Quitman	2.99	Waynesboro	0.00
Hawaii (for April)	70.1	.....	Mahukona	89	13	Waimea	47	7	7.45	.....	Waiakamoi	37.86	Makapun	0.23
Idaho	56.5	+2.7	2 stations	100	31	Challis	16	5	1.27	−0.48	Castle Creek	3.65	Shoshone	0.17
Illinois	65.3	+2.4	Golconda	97	26	Joliet	29	2	2.32	−1.65	Antioch	6.76	Fairfield	0.12
Indiana	64.6	+3.1	Shoals	100	30	3 stations	29	1†	2.64	−1.41	Knox	8.15	Decker	0.34
Iowa	62.2	+1.7	Cedar Rapids	96	26	Washta	25	13	3.31	−1.26	Fairfield	6.90	Leon	0.30
Kansas	64.3	+0.6	Wallace	98	9	4 stations	28	13	3.35	−0.89	Minneola	8.16	Lawrence	0.64
Kentucky	66.5	+0.8	Beaver Dam	103	28	Greensburg	32	1	2.16	−1.76	Bowling Green	4.65	Louisville	0.65
Louisiana	73.8	−0.3	Angola	99	31	Collinston	43	9	2.33	−1.42	Lake Charles	10.11	Hammond	T.
Maryland & Delaware	65.2	+1.9	Cambridge	100	27	Deer Park	18	1	2.06	−1.57	State Sanatorium	4.24	Wilmington	0.89
Michigan	57.0	+3.1	Bay City	94	29	3 stations	20	3†	3.37	+0.15	Allegan	11.34	Iron Mountain	0.43
Minnesota	57.6	+3.1	Tracy	103	26	2 stations	20	12†	2.89	−0.56	Worthington	6.85	State Sanatorium	0.30
Mississippi	71.5	−0.4	Columbus	100	30	Porterville	40	14	1.83	−2.59	Greenville	5.30	Pascagoula	0.00
Missouri	66.6	+2.0	Grant City	98	26	Cassville	31	9	1.47	−3.40	Dean	4.71	Wheatland	0.16
Montana	52.5	+1.3	4 stations	91	31	2 stations	15	5†	1.89	−0.54	Highwood	4.28	Medicine Lake	0.25
Nebraska	60.7	+1.4	Ewing	100	26	Hillside	22	8	2.68	−0.87	Norfolk	5.98	Scottsbluff	0.72
Nevada	59.4	+3.5	Leeland	111	21	Geyser	10	2	0.53	−0.43	Jack Creek	2.12	6 stations	0.00
New England	56.8	+1.7	Durham, N. H.	99	27	Keene, N. H.	21	2	2.15	−1.46	Hyannis, Mass.	4.79	Burlington, Vt.	0.36
New Jersey	63.1	+2.8	4 stations	98	27	2 stations	30	1	2.57	−1.30	Sussex	5.09	Bridgeton	0.95
New Mexico	60.1	+0.1	Almagordo (near)	99	29	Luna	15	2	2.62	+1.14	Portales	12.67	2 stations	0.03
New York	58.0	+2.1	2 stations	98	27	2 stations	20	1†	3.08	−0.06	Allegany	7.50	Harkness	0.44
North Carolina	67.9	+0.6	5 stations	101	28	Banner Elk	29	2	1.38	−2.73	Newbern	3.55	Elizabethtown	0.00
North Dakota	55.2	+2.1	3 stations	95	24†	McLeod	16	16	2.12	−0.45	Turtle Lake	4.21	Howard	0.86
Ohio	62.2	+1.4	Brilliant	102	29	Lisbon	26	1†	3.11	−0.36	Antwerp	8.45	Dayton	0.94
Oklahoma	66.9	−0.6	Goodwell	96	10	Newkirk	36	13	5.10	−0.76	Geary	8.67	Stillwater	2.04
Oregon	56.7	+3.3	Cliff	98	30	Whitaker	8	4	1.46	−0.90	Waldo Lake	3.80	Prineville	0.06
Pennsylvania	61.5	+1.6	3 stations	96	26†	2 stations	19	1	3.34	−0.53	Lawrenceville	6.52	Philadelphia	0.90
Porto Rico	76.7	−0.4	Canóvanas	96	2	.....do	52	5†	11.42	+3.99	Rio Grande	28.85	Santa Isabel	2.26
South Carolina	72.1	+0.6	2 stations	105	28	.....do	42	3	0.83	−2.54	Ferguson	2.70	Edgefield	0.00
South Dakota	57.5	+1.5	Timber Lake	98	30	Sorum	22	12	3.10	+0.48	Forestburg	8.94	Pine Ridge	0.70
Tennessee	67.5	+0.4	Dunlap	101	29	Mountain City	33	2†	2.19	−1.86	Johnsonville	4.73	Chattanooga	0.57
Texas	71.3	−1.5	Eagle Pass	105	5†	4 stations	40	12†	7.68	+4.14	Beaumont	19.35	Alpine	0.50
Utah	58.2	+3.0	St. George	101	29	Fruitland	17	5	0.65	−0.61	Lower Mill Creek	2.11	4 stations	0.00
Virginia	65.6	+1.6	2 stations	98	27†	Mount Weather	26	4	1.64	−2.40	Petersburg	3.73	Radford	0.58
Washington	57.1	+2.3	Prosser	98	31	Republic	16	28	1.14	−1.05	Quiniault	3.65	Eltopia	0.08
West Virginia	62.4	+0.1	2 stations	100	29	Marlinton	23	1	1.96	−2.03	Point Pleasant	3.70	2 stations	0.55
Wisconsin	57.8	+2.9	New Richmond	98	25	Ashland (1)	20	12†	3.53	−0.20	Cottage Grove	8.54	Hayward	0.19
Wyoming	50.1	+2.2	Wheatland	92	30	Thumb, Y. N. P.	4	5	1.47	−0.84	Bechler River, Y. N. P.	3.74	Basin	0.17

DESCRIPTION OF TABLES AND CHARTS.

Table I gives the data ordinarily needed for climatological studies for about 158 Weather Bureau stations making simultaneous observations at 8 a. m. and 8 p. m., seventy-fifth meridian time daily, and for about 41 others making only one observation. The altitudes of the instruments above ground are also given.

Table II gives a record of precipitation the intensity of which at some period of the storm's continuance equaled or exceeded the following rates:

Duration (minutes)	5	10	15	20	25	30	35	40	45	50	60
Rates per hour (inches)	3.00	1.80	1.40	1.20	1.08	1.00	0.94	0.90	0.87	0.84	0.80

In cases where no storm of sufficient intensity to entitle it to a place in the full table has occurred, the greatest precipitation of any single storm has been given, also the greatest hourly fall during that storm.

Table III gives, for about 30 stations of the Canadian Meteorological Service, the means of pressure and temperature, total precipitation and depth of snowfall, and the respective departures from normal values, except in the case of snowfall.

Chart I.—Hydrographs for several of the principal rivers of the United States.

Chart II.—Tracks of centers of high areas; and

Chart III.—Tracks of centers of low areas. The roman numerals show the chronological order of the centers. The figures within the circles show the days of the month; the letters *a* and *p* indicate, respectively, the observations at 8 a. m and 8 p. m., seventy-fifth meridian time. Within each circle is also given (Chart II) the last three figures of the highest barometric reading and (Chart III) the lowest reading reported at or near the center at that time, and in both cases as reduced to sea level and standard gravity.

Chart IV.—Total precipitation. The scale of shades showing the depth is given on the chart. Where the monthly amounts are too small to justify shading, and over sections of the country where stations are too widely separated or the topography is too diversified to warrant reasonable accuracy in shading, the actual depths are given for a limited number of representative stations. Amounts less than 0.005 inch are indicated by the letter T, and no precipitation by 0.

Chart V.—Percentage of clear sky between sunrise and sunset. The average cloudiness at each Weather Bureau station is determined by numerous personal observations between sunrise and sunset. The difference between the observed cloudiness and 100 is assumed to represent the percentage of clear sky, and the values thus obtained are the basis of this chart. The chart does not relate to the nighttime.

Chart VI.—Isobars and isotherms at sea level and prevailing wind directions. The pressures have been reduced to sea level and standard gravity by the method described by Prof. Frank H. Bigelow on pages 13–16 of

the REVIEW for January, 1902. The pressures have also been reduced to the mean of the 24 hours by the application of a suitable correction to the mean of the 8 a. m. and 8 p. m. readings at stations taking two observations daily, and to the 8 a. m. or the 8 p. m. observations, respectively, at stations taking but a single observation. The diurnal corrections so applied will be found in the Annual Report of the Chief of the Weather Bureau, 1900–1901, volume 2, Table 27, pages 140–164.

The isotherms on the sea-level plane have been constructed by means of the data summarized in chapter 8 of volume 2 of the annual report just mentioned. The correction $t_0 - t$, or temperature on the sea-level plane minus the station temperature as given by Table 48 of that report, is added to the observed surface temperature to obtain the adopted sea-level temperature.

The prevailing wind directions are determined from hourly observations at the great majority of the stations; a few stations having no self-recording wind-direction apparatus determine the prevailing direction from the daily or twice-daily observations only.

Chart VII.—Total snowfall. This is based on the reports from regular and cooperative observers and shows the depth in inches and tenths of the snowfall during the month. In general, the depth is shown by lines inclosing areas of equal snowfall, but in special cases figures are also given.

Chart VIII.—Depth of snow on ground at end of the month, expressed in inches and tenths.

Charts VII and VIII are published only when the general snow cover is sufficiently extensive to justify their preparation.

TABLE I.—*Climatological data for United States Weather Bureau stations, May, 1914.*

Districts and stations.	Elevation of instruments.			Pressure in inches.			Temperature of the air, in degrees Fahrenheit.											Mean wet thermometer.	Mean temperature of the dew point.	Mean relative humidity, per cent.	Precipitation, inches.			Wind.				Clear days.	Partly cloudy days.	Cloudy days.	Average cloudiness, tenths.	Total snowfall.	Snow on ground at end of month.
	Barometer above sea level, feet.	Thermometer above ground.	Anemometer above ground.	Station, reduced to mean of 24 hours.	Sea level, reduced to mean of 24 hours.	Departure from normal.	Mean max.+mean min.÷2.	Departure from normal.	Maximum.	Date.	Mean maximum.	Minimum.	Date.	Mean minimum.	Greatest daily range.						Total.	Departure from normal.	Days with 0.01 or more.	Total movement, miles.	Prevailing direction.	Maximum velocity. Miles per hour.	Maximum velocity. Direction.	Maximum velocity. Date.						
New England.							56.6	+ 2.0												71	2.08	− 1.3								5.1		
Eastport	76	67	85	29.92	30.01	+ .05	48.4	+ 1.5	87	27	57	29	2	40	40	44	41	78	0.80	− 3.0	8	7,011	s.	44	ne.	9	5	13	13	6.8	T.	....
Greenville	1,070	6	....	28.84	30.01	.....	52.1	.....	87	27	64	23	1	40	43	....	....	....	1.70	.....	8	.....	se.	.....	.....	.....	.....	.....	.....	.....	0.1	....
Portland, Me	103	82	117	29.91	30.04	+ .07	55.4	+ 1.9	92	26	64	33	13	46	35	48	42	66	2.02	− 1.6	7	6,960	sw.	31	ne.	9	12	5	14	5.7	T.	....
Concord	288	70	79	29.73	30.04	+ .06	57.0	+ 1.3	93	27	70	32	16	44	39	....	....	....	1.54	− 1.7	6	4,222	nw.	25	nw.	28	17	6	8	4.4	0.5	....
Burlington	404	11	48	29.61	30.04	+ .07	57.2	+ 3.3	90	27	68	32	1	46	32	....	....	....	0.36	− 2.5	7	7,732	s.	39	s.	30	12	12	7	4.8	.....	....
Northfield	876	12	60	29.10	30.05	+ .08	53.2	− 0.3	87	27	67	24	2	39	41	51	48	79	0.90	− 1.9	9	5,612	s.	32	n.	1	15	8	8	4.5	.....	....
Boston	125	115	188	29.90	30.04	+ .06	60.4	+ 3.8	95	27	70	38	1	51	29	52	46	65	2.78	− 0.8	7	7,305	w.	29	e.	13	10	11	10	5.3	.....	....
Nantucket	12	14	90	30.02	30.03	+ .04	53.6	+ 0.6	77	28	61	35	1	46	22	49	46	81	3.38	+ 0.7	11	10,912	sw.	42	n.	6	13	10	8	5.2	.....	....
Block Island	26	11	46	30.01	30.04	+ .05	54.8	+ 1.9	79	28	62	38	1	47	23	50	48	83	3.51	− 0.2	7	11,541	sw.	46	sw.	27	12	11	8	4.9	.....	....
Narragansett Pier	.....	9	....	.....	.....	.....	56.5	+ 1.8	86	28	66	31	1	47	35	....	....	....	3.08	.....	8	.....	sw.	.....	.....	.....	18	5	8	.....	.....	....
Providence	160	215	251	29.87	30.04	+ .06	59.7	+ 1.2	90	26	70	35	1	49	35	53	47	68	1.88	− 1.6	8	9,666	nw.	48	nw.	1	14	10	7	4.8	.....	....
Hartford	159	122	140	29.87	30.04	+ .06	61.4	+ 3.9	94	27	72	37	1	50	31	52	45	58	2.71	− 0.8	7	5,219	nw.	40	sw.	27	10	9	12	5.5	.....	....
New Haven	106	117	155	29.93	30.04	+ .05	61.0	+ 3.4	90	27	71	38	1	51	28	53	47	63	3.00	− 0.6	8	6,366	nw.	40	w.	27	14	9	8	4.7	.....	....
Middle Atlantic States.							64.4	+ 2.9												61	2.00	− 1.5								4.1		
Albany	97	102	115	29.94	30.04	+ .06	61.7	+ 2.8	94	26	73	36	2	50	36	53	46	60	2.30	− 0.7	6	5,363	nw.	26	se.	29	19	8	4	3.3	.....	....
Binghamton	871	10	69	29.16	30.08	+ .10	59.4	+ 2.4	92	26	71	32	1	48	36	....	....	....	4.51	+ 1.4	12	3,630	nw.	26	sw.	27	13	12	6	4.6	.....	....
New York	314	414	454	29.72	30.05	+ .06	63.6	+ 4.3	91	27	73	40	1	54	29	53	44	55	1.97	− 1.2	8	11,392	nw.	90	nw.	27	12	11	8	5.0	.....	....
Harrisburg	374	94	104	29.69	30.09	+ .11	65.3	+ 3.6	92	26	76	42	1	55	31	56	48	59	2.61	− 1.1	7	4,337	w.	30	sw.	27	12	12	7	4.5	.....	....
Philadelphia	117	123	184	29.95	30.08	+ .09	66.8	+ 4.6	94	27	76	43	1	57	27	57	49	58	0.90	− 2.3	5	7,387	nw.	46	nw.	27	11	13	7	4.7	.....	....
Reading	325	81	98	29.73	30.08	.....	64.8	.....	94	26	76	38	1	54	32	55	48	58	1.20	.....	8	4,682	nw.	28	se.	12	13	10	8	4.7	.....	....
Scranton	805	111	119	29.23	30.08	+ .10	61.5	+ 2.7	92	26	73	35	3	50	36	54	49	68	3.29	− 0.2	12	4,919	n.	30	nw.	27	13	13	5	4.1	.....	....
Atlantic City	52	37	48	30.02	30.08	+ .10	61.0	+ 3.5	90	28	69	38	1	53	26	54	49	68	1.27	− 1.7	5	5,629	sw.	25	sw.	5	14	10	7	4.3	.....	....
Cape May	17	13	49	30.08	30.10	+ .11	62.8	+ 4.2	91	27	71	43	2	54	30	56	52	74	2.15	− 0.8	5	5,846	nw.	30	e.	12	15	11	5	3.8	.....	....
Trenton	190	159	183	29.85	30.05	.....	64.1	.....	94	27	75	39	1	53	32	54	47	58	1.98	− 1.5	8	7,692	nw.	35	e.	12	14	11	6	4.3	.....	....
Baltimore	123	100	113	29.95	30.08	+ .09	68.0	+ 3.8	94	27	78	43	1	58	33	57	49	54	1.17	− 2.4	6	4,945	nw.	34	n.	27	15	11	5	3.7	.....	....
Washington	112	62	85	29.96	30.08	+ .08	67.0	+ 2.8	95	27	78	41	1	55	39	58	51	60	1.72	− 2.1	7	4,692	nw.	36	n.	27	14	11	6	4.3	.....	....
Lynchburg	681	83	88	29.36	30.10	+ .10	68.4	+ 2.5	96	28	81	38	1	55	38	58	52	59	0.59	− 3.4	4	5,069	n.	28	nw.	9	15	15	1	4.0	.....	....
Mount Weather	1,725	10	75	28.28	30.07	+ .07	63.1	+ 3.6	88	27	72	35	1	54	26	53	46	58	1.07	− 2.7	7	11,036	nw.	52	nw.	5	9	12	10	5.4	.....	....
Norfolk	91	170	205	30.01	30.10	+ .10	68.3	+ 2.1	94	28	77	48	2	59	26	60	54	64	2.53	− 1.5	7	8,700	sw.	38	sw.	5	18	8	5	3.3	.....	....
Richmond	144	11	52	29.95	30.10	+ .11	68.6	+ 1.3	95	27	81	41	1	57	32	59	52	60	2.50	− 1.4	5	5,468	s.	30	ne.	30	18	10	3	3.1	.....	....
Wytheville	2,293	40	47	27.78	30.13	+ .14	61.0	− 0.4	88	29	75	33	1	47	42	54	49	66	1.38	− 2.5	6	3,361	w.	20	w.	5	21	9	1	2.2	.....	....
South Atlantic States.							71.1	+ 1.3												64	0.75	− 3.0								3.6		
Asheville	2,255	70	84	27.82	30.14	+ .15	63.4	+ 0.8	91	28	76	39	19	51	37	54	47	60	0.71	− 3.1	6	5,261	nw.	44	se.	29	16	12	3	3.8	.....	....
Charlotte	773	68	76	29.30	30.12	+ .13	70.6	+ 2.2	95	28	82	47	1	59	34	59	51	55	0.49	− 3.4	5	4,969	sw.	36	w.	5	15	13	3	3.3	.....	....
Hatteras	11	12	50	30.09	30.10	+ .09	69.2	+ 2.1	85	29	75	48	2	63	20	63	60	75	0.67	− 3.5	5	10,111	sw.	55	w.	5	23	6	2	2.5	.....	....
Manteo	12	12	46	.....	.....	.....	66.6	.....	91	28	76	37	2	57	....	....	....	....	1.14	.....	2	.....	ne.	.....	.....	.....	22	7	2	.....	.....	....
Raleigh	376	103	110	29.71	30.10	+ .11	70.2	+ 2.1	98	28	81	45	1	59	29	59	50	55	1.20	− 3.7	5	5,760	sw.	43	w.	5	20	9	2	3.1	.....	....
Wilmington	78	81	91	30.05	30.13	+ .12	70.4	+ 1.3	91	28	80	49	2	60	30	61	56	67	0.10	− 3.9	3	6,471	sw.	38	sw.	5	17	14	0	2.7	.....	....
Charleston	48	11	92	30.08	30.13	+ .12	72.5	+ 0.1	94	29	80	55	9	65	27	65	61	73	0.82	− 2.6	5	8,696	s.	43	ne.	18	21	6	4	2.8	.....	....
Columbia, S. C	351	41	57	29.75	30.13	+ .13	73.2	+ 1.4	99	28	85	52	1	61	33	60	52	55	0.55	− 2.6	5	5,530	sw.	40	sw.	5	18	11	2	3.2	.....	....
Augusta	180	89	97	29.94	30.13	+ .14	73.6	+ 1.4	99	29	86	50	10	62	34	61	53	54	0.06	− 3.2	3	5,119	e.	40	nw.	7	10	11	10	5.2	.....	....
Savannah	65	150	194	30.06	30.13	+ .14	73.3	+ 0.8	94	29	82	55	9	64	29	66	62	76	0.89	− 2.1	4	9,745	sw.	70	w.	7	16	12	3	3.7	.....	....
Jacksonville	43	96	129	30.08	30.12	+ .12	74.8	+ 0.6	92	6	83	59	9	66	24	66	63	72	2.00	− 2.2	5	7,684	ne.	48	sw.	8	11	9	11	5.3	.....	....
Florida Peninsula.							77.9	+ 0.2												76	2.09	− 2.2								5.8		
Key West	22	10	64	30.02	30.04	+.07	78.9	− 0.1	86	14	84	69	18	74	15	72	70	76	3.41	0.0	10	8,479	e.	29	ne.	20	7	12	12	6.2	.....	....
Miami	25	37	72	30.05	30.08	.....	77.6	− 1.0	87	9	83	63	2	72	20	71	68	73	1.82	− 4.6	9	8,042	e.	32	ne.	20	3	12	16	7.1	.....	....
Sand Key	23	39	72	29.99	30.02	+ .05	77.5	.....	85	8	80	71	27	75	8	74	72	83	2.95	.....	11	12,304	e.	47	se.	27	8	15	8	5.1	.....	....
Tampa	35	79	96	30.06	30.09	+ .10	77.2	+ 1.7	91	24	86	60	10	68	26	69	65	73	1.03	− 1.9	3	6,213	ne.	29	ne.	19	10	17	4	5.0	.....	....
Titusville	44	6	....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	....
East Gulf States.							72.9	+ 0.6												62	0.69	− 2.8								4.3		
Atlanta	1,174	190	216	28.92	30.15	+ .16	71.2	+ 1.7	97	29	81	48	9	61	26	59	51	55	0.30	− 2.8	3	7,893	nw.	44	w.	5	20	5	6	3.5	.....	....
Macon	370	78	87	29.73	30.12	+ .13	73.4	+ 2.3	98	29	86	49	10	61	35	62	54	57	0.45	− 2.4	4	4,634	s.	38	nw.	7	20	9	2	3.0	.....	....
Thomasville	273	8	57	29.82	30.11	+ .12	75.2	+ 1.2	100	30	88	51	10	62	35	64	60	67	1.45	− 2.6	5	4,226	e.	22	sw.	5	12	13	6	4.3	.....	....
Pensacola	56	140	182	30.05	30.11	+ .12	74.2	− 0.6	86	30	80	55	9	68	23	66	62	71	0.09	− 2.6	1	9,326	se.	35	e.	20	10	12	9	5.0	.....	....
Anniston	741	9	57	29.37	30.16	+ .17	69.2	+ 0.8	97	29	82	44	16	56	35	....	....	....	0.84	− 2.2	4	3,735	se.	24	w.	5	20	6	5	3.1	.....	....
Birmingham	700	11	48	29.39	30.15	+ .17	70.6	− 1.0	97	30	82	46	9	60	31	60	53	59	1.52	− 1.6	5	4,415	n.	27	s.	4	19	6	6	3.8	.....	....
Mobile	57	125	161	30.05	30.11	+ .12	74.8	+ 1.2	92	7	84	53	9	66	25	66	62	71	0.22	− 3.8	2	7,184	sw.	28	e.	20	8	20	3	4.3	.....	....
Montgomery	223	100	112	29.88	30.12	+ .13	73.6	+ 0.1	98	30	85	52	9	62	29	62	55	57	0.69	− 3.1	5	4,872	ne.	30	nw.	7	16	12	3	3.4	.....	....
Meridian	375	85	93	29.72	30.11	+ .13	70.9	− 0.2	96	30	82	46	9	60	34	63	58	68	0.79	− 3.1	4	3,600	ne.	19	e.	20	8	12	11	6.1	.....	....
Vicksburg	247	62	74	29.84	30.12	+ .15	73.4	+ 0.5	92	30	84	51	14	63	29	63	58	65	1.02	− 3.2	6	4,767	se.	29	nw.	7	13	7	11	5.2	.....	....
New Orleans	51	90	121	30.04	30.09	+ .12	75.5	+ 1.0	92	31	83	59	9	68	21	68	65	75	0.19	− 3.7	3	5,843	ne.	31	s.	4	8	12	11	5.6	.....	....
West Gulf States.							72.0	− 0.9												78	5.53	− 1.4								6.2		
Shreveport	249	77	93	29.83	30.10	+ .15	72.5	− 0.7	90	31	81	55	14	64	26	65	62	75	4.49	+ 0.3	8	5,000	se.	27	s.	29	10	8	13	5.5	.....	....
Bentonville	1,303	11	44	28.74	30.10	+ .17	66.0	− 0.4	87	25	77	38	13	55	36	....	....	....	2.19	− 3.0	9	3,101	s.	21	s.	10	11	14	6	4.8	.....	....
Fort Smith	457	79	94	29.60	30.08	+ .15	69.6	− 0.1	91	31	80	47	13	60	38	62	57	70	4.75	− 0.2	13	5,687	e.	39	n.	11	8	9	14	6.2	.....	....
Little Rock	357	139	147	29.74	30.11	+ .16	70.6	+ 0.2	91	31	80	49	13	62	32	62	57	66	2.25	− 2.8	6	6,176	s.	28	n.	12	10	18	3	4.8	.....	....
Brownsville	57	3	40	.....	.....	.....	78.7	.....	94	4	85	67	14	72	19	....	....	....	9.03	.....	12	.....	e.	.....	.....	.....	.....	.....	.....	.....	.....	.....	....
Corpus Christi	20	69	77	29.99	30.01	+ .11	76.2	− 0.3	90	4	80	63	13	73	15	73	71	88	3.17	+ 0.4	12	11,121	se.	52	e.	3	2	17	12	6.7	.....	....
Dallas	512	109	117	29.52	30.06	.....	71.0	.....	90	5	79	51	13	63	26	....	....	....	7.10	.....	15	7,080	se.	34	se.	10	4	11	16	6.6	.....	....
Fort Worth	670	106	114	29.33	30.04	+ .13	70.2	− 3.0	91	5	78	50	13	62	29	64	62	80	10.71	+ 6.6	16	7,169	e.	34	s.	10	3	11	17	7.2	.....	....
Galveston	54	106	114	30.01	30.07	+ .13	74.6	− 0.8	82	7	78	62	14	71	14	70	68	84	7.54	+ 4.3	8	10,062	se.	42	s.	4	7	12	12	6.1	.....	....
Houston	138	111	121	29.90	30.04	.....	74.4	− 1.1	91	5	82	60	14	67	23	....	....	....	15.47	.....	12	6,935	se.	35	ne.	12	7	12	12	6.2	.....	....
Palestine	510	64	72	29.53	30.06	+ .13	71.8	− 0.7	90	6	80	54	14	64	25	66	63	81	6.16	+ 1.3	11	5,333	s.	36	se.	2	8	8	15	6.3	.....	....
San Antonio	701	80	91	29.30	30.02	+ .12	74.4	− 0.4	92	7	82	57	13	66	28	68	66	83	5.59	+ 2.6	14	4,119	se.	25	n.	13	4	16	11	6.4	.....	....
Taylor	582	55	63	29.44	30.05	+ .14	72.0	− 2.3	92	5	80	54	13	64	29	....	....	....	8.41	+ 4.4	17	6,577	se.	40	ne.	16	3	16	12	7.0	.....	....

TABLE I.—*Climatological data for United States Weather Bureau stations, May, 1914*—Continued.

Districts and stations.	Elevation of instruments.			Pressure in inches.			Temperature of the air, in degrees Fahrenheit.										Mean wet thermometer.	Mean temperature of the dew point.	Mean relative humidity, per cent.	Precipitation, inches.			Wind.					Clear days.	Partly cloudy days.	Cloudy days.	Average cloudiness, tenths.	Total snowfall.	Snow on ground at end of month.
	Barometer above sea level, feet.	Thermometer above ground.	Anemometer above ground.	Station, reduced to mean of 24 hours.	Sea level, reduced to mean of 24 hours.	Departure from normal.	Mean max. + mean min. ÷ 2.	Departure from normal.	Maximum.	Date.	Mean maximum.	Minimum.	Date.	Mean minimum.	Greatest daily range.					Total.	Departure from normal.	Days with 0.01 or more.	Total movement, miles.	Prevailing direction.	Maximum velocity. Miles per hour.	Maximum velocity. Direction.	Maximum velocity. Date.						
Ohio Valley and Tennessee.							**66.2**	**+ 1.1**								**61**				**1.74**	**− 1.9**								**4.1**		
Chattanooga	762	189	213	29.35	30.16	+ .17	69.4	+ 0.8	95	29	81	49	1	58	33	58	50	54	0.57	− 3.0	4	5,517	ne.	36	sw.	5	16	10	5	4.0	.....	.....
Knoxville	996	93	100	29.09	30.14	+ .15	68.1	+ 1.6	95	29	80	45	15	56	34	58	50	57	1.25	− 2.4	7	3,512	ne.	30	w.	7	15	8	8	4.2	.....	.....
Memphis	399	76	97	29.73	30.16	+ .20	70.6	− 0.1	91	26	80	47	1	61	24	61	55	62	4.64	+ 0.3	5	5,601	sw.	38	sw.	4	14	9	8	4.7	.....	.....
Nashville	546	163	191	29.57	30.15	+ .17	68.2	− 0.6	95	29	80	45	1	57	32	58	52	59	3.01	− 0.5	4	5,948	n.	46	w.	7	15	10	6	4.3	.....	.....
Lexington	989	75	102	29.08	30.15	+ .16	65.8	+ 1.5	92	28	76	37	1	56	29	.....	.....	.....	1.65	− 1.9	4	6,858	s.	42	nw.	7	14	12	5	3.8	.....	.....
Louisville	525	219	255	29.56	30.14	+ .16	67.8	+ 1.1	93	28	78	42	1	57	27	58	52	60	0.65	− 3.0	4	7,719	s.	60	w.	7	16	10	5	3.8	.....	.....
Evansville	431	72	82	29.66	30.13	+ .16	67.9	+ 0.8	93	31	78	42	1	58	27	58	51	58	1.03	− 2.4	4	5,280	s.	32	sw.	11	18	9	4	3.9	.....	.....
Indianapolis	822	154	164	29.24	30.12	+ .15	65.6	+ 2.3	91	28	76	38	1	56	28	56	49	58	1.90	− 2.0	6	6,673	sw.	36	sw.	25	15	9	7	4.2	.....	.....
Terre Haute	575	96	129	29.49	30.11	.....	66.6	.....	92	27	78	37	1	55	34	57	51	60	1.01	.....	6	6,894	s.	41	nw.	7	12	15	4	4.9	.....	.....
Cincinnati	628	152	160	29.45	30.13	+ .14	66.8	+ 1.7	94	28	77	39	1	56	30	59	53	64	1.83	− 1.7	6	4,183	sw.	30	w.	7	16	8	7	3.8	.....	.....
Columbus	824	173	222	29.25	30.12	+ .14	63.8	+ 1.5	94	29	75	34	1	53	33	56	51	66	1.28	− 2.4	7	7,142	nw.	36	nw.	5	17	8	6	3.6	.....	.....
Dayton	899	181	216	29.16	30.10	.....	64.4	+ 1.5	92	28	75	35	1	54	30	56	49	63	0.94	− 2.9	5	6,620	sw.	42	w.	7	18	9	4	3.5	.....	.....
Pittsburgh	842	353	410	29.21	30.11	+ .12	62.8	+ 0.2	90	29	73	37	1	52	37	54	48	61	2.64	− 0.7	10	6,625	nw.	68	nw.	11	14	6	11	4.7	.....	.....
Elkins	1,940	41	50	28.10	30.13	+ .13	60.1	+ 1.0	90	29	75	29	1	45	44	53	47	66	1.43	− 2.6	8	2,745	w.	29	w.	12	9	13	9	5.2	.....	.....
Parkersburg	638	77	84	29.49	30.14	+ .15	64.8	+ 1.5	96	29	77	38	1	52	35	56	50	64	1.51	− 2.0	5	3,406	nw.	47	nw.	12	19	7	5	3.2	.....	.....
Lower Lake Region.							**59.2**	**+ 1.7**								**67**				**3.62**	**+ 0.5**								**4.3**		
Buffalo	767	247	280	29.26	30.10	+ .13	54.2	− 0.3	85	29	61	34	1	47	25	50	46	78	3.67	+ 0.6	15	10,960	sw.	58	sw.	27	14	11	6	4.5	.....	.....
Canton	448	10	61	29.58	30.06	.....	57.2	+ 1.0	85	27	68	30	2	46	34	.....	.....	.....	0.89	− 2.0	9	8,373	sw.	42	w.	31	20	6	5	3.1	.....	.....
Oswego	335	76	91	29.70	30.06	+ .09	55.4	+ 0.7	84	26	64	37	1	47	32	50	44	67	2.32	− 0.5	10	6,735	w.	27	sw.	27	14	10	7	4.2	.....	.....
Rochester	523	97	113	29.52	30.10	+ .13	59.8	+ 3.1	87	25	70	35	1	50	32	51	44	61	1.79	− 1.2	9	6,552	sw.	42	sw.	27	16	7	8	4.3	.....	.....
Syracuse	597	97	113	29.44	30.09	+ .11	59.5	+ 2.2	87	26	68	35	1	51	31	52	46	63	3.05	− 0.3	11	8,005	nw.	54	sw.	27	16	7	8	4.4	.....	.....
Erie	714	92	102	29.34	30.10	+ .12	58.0	+ 0.7	87	25	66	35	1	50	24	52	46	66	5.95	+ 2.5	12	6,139	w.	40	ne.	12	10	11	10	5.1	.....	.....
Cleveland	762	190	201	29.30	30.12	+ .14	60.0	+ 1.5	90	29	68	38	1	52	26	54	49	68	4.09	+ 0.9	12	7,792	se.	49	ne.	12	11	12	8	4.6	.....	.....
Sandusky	629	62	70	29.43	30.11	+ .13	61.4	+ 2.2	92	29	70	40	1	53	29	53	48	65	4.03	+ 0.8	12	7,655	sw.	42	n.	11	11	9	11	5.3	.....	.....
Toledo	628	208	246	29.44	30.12	+ .15	62.4	+ 2.7	90	26	72	34	1	53	27	54	48	64	5.98	+ 2.7	9	9,923	sw.	42	nw.	11	16	10	5	3.8	.....	.....
Fort Wayne	856	113	124	29.20	30.12	.....	62.7	+ 2.5	90	28	73	36	1	53	30	56	52	72	5.21	.....	8	5,820	sw.	29	sw.	25	19	4	8	3.8	.....	.....
Detroit	730	218	245	29.32	30.11	+ .14	60.8	+ 2.9	89	26	70	34	1	51	27	52	46	62	4.44	+ 1.2	12	8,189	w.	45	nw.	29	15	10	6	4.2	.....	.....
Upper Lake Region.							**56.3**	**+ 3.7**								**68**				**3.28**	**− 0.2**								**4.5**		
Alpena	609	13	92	29.43	30.10	+ .13	54.5	+ 5.0	90	26	66	30	1	44	37	48	43	65	2.71	− 0.6	7	7,739	se.	36	w.	29	10	18	3	4.5	.....	.....
Escanaba	612	54	60	29.41	30.08	+ .11	53.2	+ 3.2	91	26	62	31	11	44	34	48	43	74	0.80	− 2.6	10	7,463	s.	32	ne.	11	13	12	6	4.8	T.	.....
Grand Haven	632	54	92	29.41	30.09	+ .13	55.7	+ 0.9	80	28	64	36	15	47	26	50	44	67	4.75	+ 1.4	16	7,994	sw.	32	s.	25	17	10	4	3.4	.....	.....
Grand Rapids	707	70	87	29.34	30.10	+ .13	60.0	+ 1.0	88	25	70	36	2	50	30	53	48	68	3.06	− 0.3	13	4,557	w.	35	nw.	26	12	14	5	4.2	.....	.....
Houghton	684	62	72	29.32	30.05	+ .08	53.9	+ 4.2	88	25	65	31	11	43	38	.....	.....	.....	1.87	− 1.4	9	5,986	w.	50	nw.	25	12	10	9	4.5	T.	.....
Lansing	878	11	62	29.16	30.11	.....	58.6	+ 0.7	87	26	71	30	1	46	34	52	47	68	4.66	+ 1.1	11	4,314	sw.	37	nw.	14	11	11	9	4.8	.....	.....
Ludington	637	60	66	29.39	30.09	.....	53.6	.....	79	28	61	35	2	46	22	49	44	71	3.54	.....	14	8,121	s.	31	sw.	25	13	14	4	4.1	.....	.....
Marquette	734	77	111	29.28	30.09	+ .12	54.4	+ 5.4	92	25	64	32	10	45	38	47	40	62	0.90	− 2.4	10	8,169	nw.	40	sw.	25	17	6	8	4.3	T.	.....
Port Huron	638	70	120	29.40	30.10	+ .13	57.4	+ 3.7	88	29	68	33	1	47	34	51	45	67	1.91	− 1.3	13	7,021	sw.	34	w.	29	10	17	4	4.5	.....	.....
Saginaw	641	48	82	29.41	30.10	.....	58.8	.....	87	29	71	31	1	47	33	52	47	68	3.95	− 0.2	11	6,751	sw.	32	sw.	29	13	13	5	4.3	.....	.....
Sault Sainte Marie	614	11	61	29.40	30.10	+ .15	52.7	+ 5.0	85	25	65	29	1	40	37	46	40	67	1.08	− 2.2	8	6,435	w.	38	sw.	25	10	12	9	5.3	.....	.....
Chicago	823	140	310	29.23	30.11	+ .15	62.3	+ 5.8	92	26	70	40	12	54	36	53	47	63	5.22	+ 1.8	13	8,860	sw.	42	sw.	3	17	9	5	3.9	.....	.....
Green Bay	617	109	144	29.39	30.05	+ .10	58.4	+ 3.9	88	26	68	35	15	49	27	52	47	68	4.42	+ 0.8	11	9,378	s.	46	ne.	11	7	18	6	5.7	.....	.....
Milwaukee	681	119	133	29.36	30.09	+ .13	57.8	+ 4.2	89	26	67	36	12	49	34	50	45	67	6.01	+ 2.6	15	6,142	sw.	36	sw.	25	14	10	7	4.3	.....	.....
Duluth	1,133	11	47	28.83	30.05	+ .09	53.2	+ 4.6	85	25	64	29	11	43	42	49	46	77	4.63	+ 1.2	13	9,507	ne.	56	sw.	25	13	10	8	4.5	T.	.....
North Dakota.							**55.6**	**+ 1.4**								**64**				**1.92**	**− 0.6**								**4.2**		
Moorhead	940	8	57	29.01	30.03	+ .09	57.4	+ 2.6	88	25	70	28	12	44	38	51	45	68	1.47	− 1.5	13	6,822	se.	30	s.	17	19	8	4	3.0	.....	.....
Bismarck	1,674	8	57	28.26	30.05	+ .13	55.6	+ 0.4	87	30	69	27	12	42	46	48	42	67	3.61	+ 1.1	10	9,157	nw.	49	w.	5	15	9	7	4.1	T.	.....
Devils Lake	1,482	11	44	28.41	29.98	+ .04	54.8	+ 2.1	83	30	68	23	14	42	40	47	39	62	1.42	− 0.8	9	8,376	s.	40	ne.	9	15	10	6	4.5	.....	.....
Williston	1,872	40	47	28.01	29.99	+ .06	54.6	+ 0.3	85	27	67	23	12	42	39	46	39	60	1.19	− 1.1	8	7,128	se.	39	nw.	5	11	10	10	5.3	0.5	.....
Upper Mississippi Valley.							**64.3**	**+ 2.3**								**63**				**2.68**	**− 1.5**								**4.4**		
Minneapolis	918	10	208	.....	.....	.....	60.4	.....	93	26	70	33	11	51	28	.....	.....	.....	1.80	− 2.1	9	9,280	s.	42	ne.	11	11	8	12	5.3	T.	.....
St. Paul	837	201	236	29.13	30.04	+ .10	59.9	+ 1.7	92	26	70	33	11	50	29	52	45	63	1.48	− 2.1	9	10,096	sw.	48	nw.	26	10	12	9	5.1	.....	.....
La Crosse	714	11	48	29.30	30.07	+ .13	61.4	+ 1.9	92	26	72	36	15	51	32	.....	.....	.....	2.66	− 1.1	8	4,175	s.	18	s.	25	7	13	11	5.9	.....	.....
Madison	974	70	78	29.05	30.09	+ .13	60.3	+ 2.7	87	26	70	35	12	51	31	53	47	64	5.97	+ 2.4	13	7,035	sw.	42	w.	11	9	14	8	5.2	.....	.....
Charles City	1,015	10	49	28.99	30.07	+ .13	59.9	+ 0.4	89	26	72	33	15	48	34	54	50	73	5.35	+ 0.4	12	5,826	s.	28	sw.	25	12	12	7	4.6	.....	.....
Davenport	606	71	79	29.42	30.08	+ .13	64.3	+ 2.8	91	27	75	38	12	54	31	55	48	60	1.40	− 2.8	9	5,852	sw.	30	e.	11	15	10	6	4.5	.....	.....
Des Moines	861	84	97	29.15	30.05	+ .12	64.0	+ 2.4	92	26	75	38	12	53	34	56	50	63	4.83	+ 0.3	12	6,560	s.	36	sw.	3	12	9	10	5.1	.....	.....
Dubuque	698	81	96	29.34	30.09	+ .14	62.6	+ 1.8	91	26	73	38	12	52	30	54	48	62	4.64	+ 0.3	14	4,929	s.	30	w.	25	11	12	8	4.8	.....	.....
Keokuk	614	64	78	29.42	30.09	+ .15	65.8	+ 2.6	91	27	76	40	12	55	33	58	52	65	1.73	− 2.5	10	5,291	s.	29	sw.	21	16	12	3	3.8	.....	.....
Cairo	356	87	93	29.73	30.11	+ .15	69.2	+ 1.7	92	29	79	44	1	59	27	61	57	68	2.66	− 1.2	4	5,846	s.	30	nw.	7	14	11	6	4.6	.....	.....
Peoria	609	11	45	29.44	30.11	+ .15	65.0	+ 3.3	93	28	77	37	1	53	40	56	51	65	2.28	− 2.0	8	4,957	s.	31	sw.	3	20	9	2	2.7	.....	.....
Springfield, Ill	644	10	91	29.42	30.10	+ .15	67.2	+ 3.7	93	27	79	38	1	56	32	57	50	58	1.11	− 3.4	9	6,388	s.	29	nw.	7	18	8	5	3.5	.....	.....
Hannibal	534	74	109	29.53	30.10	+ .16	66.7	+ 2.3	91	27	78	40	1	56	33	.....	.....	.....	0.95	− 4.0	5	6,557	sw.	39	sw.	11	18	10	3	3.7	.....	.....
St. Louis	567	265	303	29.50	30.10	+ .15	69.4	+ 2.9	92	27	80	44	1	59	25	58	51	56	0.69	− 3.6	7	9,950	s.	48	sw.	5	21	8	2	3.2	.....	.....
Missouri Valley.							**63.1**	**+ 1.1**								**65**				**3.03**	**− 1.2**								**5.1**		
Columbia, Mo.	781	11	84	29.28	30.10	+ .16	66.9	+ 2.4	91	26	78	40	9	56	38	.....	.....	.....	1.37	− 3.5	7	5,618	s.	37	sw.	3	6	14	11	5.8	.....	.....
Kansas City	963	161	181	29.05	30.08	+ .16	66.8	+ 2.3	88	26	76	42	12	58	38	58	51	62	0.70	− 4.4	8	8,957	s.	38	nw.	7	8	20	3	4.8	.....	.....
St. Joseph	967	11	49	29.04	30.07	.....	66.2	.....	92	26	77	40	14	56	39	57	51	63	0.55	.....	5	6,654	s.	30	nw.	7	13	12	6	4.5	.....	.....
Springfield, Mo.	1,324	98	104	28.72	30.12	+ .19	65.6	+ 1.0	87	31	75	40	13	56	33	57	52	67	3.55	− 2.0	6	7,070	s.	39	sw.	4	13	14	4	4.0	.....	.....
Iola	984	11	50	29.04	30.08	+ .16	65.6	+ 1.1	88	31	76	38	14	55	37	.....	.....	.....	5.84	+ 0.8	13	5,429	s.	31	se.	2	10	15	6	5.1	.....	.....
Topeka	983	85	101	.....	.....	.....	65.2	+ 0.2	90	26	75	37	13	55	40	.....	.....	.....	1.60	− 3.3	7	8,106	s.	37	sw.	10	9	17	5	5.1	.....	.....
Lincoln	1,189	11	84	28.78	30.03	+ .12	64.2	+ 1.3	94	25	75	34	13	53	38	56	50	66	4.20	0.0	7	8,525	s.	39	ne.	27	10	14	7	5.0	.....	.....
Omaha	1,105	115	121	28.87	30.04	+ .12	64.4	+ 1.9	93	25	75	36	12	54	37	56	50	62	2.16	− 2.3	9	6,204	s.	38	nw.	11	9	16	6	5.4	.....	.....
Valentine	2,598	47	54	27.33	30.04	+ .14	57.6	− 0.3	88	24	69	29	8	46	41	50	44	67	1.59	− 1.7	10	8,803	s.	52	sw.	25	13	7	11	5.0	T.	.....
Sioux City	1,135	94	164	28.83	30.03	+ .11	62.0	+ 1.2	95	26	73	35	12	51	37	54	48	64	3.47	− 0.9	11	10,728	s.	51	n.	23	11	13	7	5.2	.....	.....
Huron	1,306	56	67	28.66	30.06	+ .14	58.0	+ 0.7	85	26	69	31	12	47	34	51	46	68	5.83	+ 2.9	13	9,715	se.	44	w.	5	14	9	8	4.6	.....	.....
Pierre	1,572	70	75	28.39	30.05	+ .14	59.0	− 0.3	86	30	69	32	13	49	37	51	44	62	3.54	+ 1.4	11	8,550	e.	48	w.	5	12	9	10	5.3	.....	.....
Yankton	1,233	49	57	28.72	30.02	+ .10	61.4	+ 1.4	95	26	72	35	12	50	37	.....	.....	.....	2.52	− 1.4	10	6,957	nw.	34	s.	9	8	12	11	6.2	.....	.....

TABLE I.—*Climatological data for United States Weather Bureau stations, May, 1914*—Continued.

Districts and stations.	Elevation of instruments.			Pressure in inches.			Temperature of the air, in degrees Fahrenheit.										Mean wet thermometer.	Mean temperature of the dew point.	Mean relative humidity, per cent.	Precipitation, inches.			Wind.				Clear days.	Partly cloudy days.	Cloudy days.	Average cloudiness, tenths.	Total snowfall.	Snow on ground at end of month.
	Barometer above sea level, feet.	Thermometer above ground.	Anemometer above ground.	Station, reduced to mean of 24 hours.	Sea level, reduced to mean of 24 hours.	Departure from normal.	Mean max.+mean min.÷2.	Departure from normal.	Maximum.	Date.	Mean maximum.	Minimum.	Date.	Mean minimum.	Greatest daily range.					Total.	Departure from normal.	Days with 0.01 or more.	Total movement, miles.	Prevailing direction.	Maximum velocity. Miles per hour.	Direction.	Date.					
Northern Slope.							54.0	+ 1.0											62	1.42	− 0.7								5.1		
Havre	2,505	11	44	27.36	29.99	+ .09	54.7	+ 0.6	87	31	68	24	7	41	45	46	37	59	1.13	− 1.0	8	6,695	nw.	35	w.	8	18	6	7	4.7	T.	....
Helena	4,110	87	114	25.82	30.00	+ .09	52.9	+ 1.3	84	31	65	32	7	41	36	44	36	59	2.30	+ 0.4	10	6,195	s.	39	s.	15	9	14	8	5.4	9.5	....
Kalispell	2,962	11	34	26.94	29.98	+ .05	53.0	+ 2.0	84	31	67	30	6	39	41	44	35	59	0.60	− 1.4	7	3,620	w.	35	w.	27	12	17	2	4.0	.....	....
Miles City	2,371	26	48	27.50	30.04	+ .13	57.4	+ 0.7	88	27	70	31	12	45	43	49	41	61	1.38	− 0.6	11	4,948	s.	36	nw.	5	12	14	5	4.3	6.0	....
Rapid City	3,234	46	50	26.64	30.05	+ .15	55.4	+ 1.2	84	24	67	30	11	44	42	48	41	64	1.61	− 1.3	13	6,671	w.	34	s.	15	10	10	11	5.6	T.	....
Cheyenne	6,088	58	64	24.05	29.98	+ .13	51.1	+ 0.1	76	30	62	27	5	40	34	43	37	66	2.10	− 0.3	11	8,292	s.	46	sw.	25	6	16	9	5.9	0.1	....
Lander	5,372	60	68	24.67	29.98	+ .10	54.0	+ 2.0	82	30	68	25	5	40	42	43	34	54	0.38	− 2.5	7	4,425	sw.	42	n.	2	6	20	5	5.3	1.6	....
Sheridan	3,790	10	47	26.14	30.03	.....	52.4	.....	81	8	66	25	7	39	49	46	39	66	3.10	.....	13	5,508	se.	46	sw.	25	8	13	10	5.7	1.4	....
Yellowstone Park	6,200	11	48	23.90	29.99	+ .08	47.9	+ 0.5	78	31	62	23	5	34	41	39	32	63	1.16	− 0.8	15	5,535	s.	37	sw.	25	9	12	10	5.1	0.2	....
North Platte	2,821	11	51	27.14	30.05	+ .17	59.8	+ 0.8	90	26	72	32	8	48	41	52	47	70	2.14	− 0.9	10	6,245	s.	31	n.	11	13	7	11	4.9	.....	....
Middle Slope.							62.6	− 0.2											68	3.60	− 0.2								5.6		
Denver	5,291	129	172	24.76	29.98	+ .14	57.4	+ 0.7	84	10	69	32	12	46	41	48	41	62	3.55	+ 1.0	15	5,453	sw.	44	n.	6	10	13	8	5.5	T.	....
Pueblo	4,685	80	86	25.32	29.96	+ .13	60.4	+ 0.9	87	9	72	36	2	48	36	48	39	54	3.51	+ 1.8	12	5,043	se.	34	nw.	22	12	11	8	4.7	.....	....
Concordia	1,398	42	50	28.59	30.06	+ .15	64.4	+ 0.7	92	25	75	35	13	54	37	57	52	69	1.70	− 3.0	6	6,235	s.	27	s.	24	4	19	8	6.4	.....	....
Dodge	2,509	11	51	27.43	30.01	+ .14	62.8	− 0.7	90	10	72	40	8	53	37	56	52	74	3.47	+ 0.1	12	8,554	se.	35	n.	11	8	14	9	5.7	.....	....
Wichita	1,358	139	158	28.62	30.04	+ .14	64.8	− 1.1	86	26	73	39	13	56	37	59	54	73	4.31	− 0.6	12	10,124	s.	44	s.	9	10	13	8	5.0	.....	....
Oklahoma	1,214	10	47	28.80	30.07	+ .18	65.8	− 2.3	84	25	74	41	13	58	29	61	58	79	5.07	− 0.7	11	10,441	s.	38	s.	10	5	12	14	6.6	.....	....
Southern Slope.							68.7	− 2.0											70	6.16	+ 3.3								5.8		
Abilene	1,738	10	52	28.23	30.02	+ .15	69.2	− 2.7	88	10	78	47	13	60	29	63	60	77	7.53	+ 3.8	14	7,813	se.	44	s.	9	5	8	18	7.3	.....	....
Amarillo	3,676	10	49	26.32	30.01	+ .17	63.2	− 1.1	95	10	74	42	12	53	36	56	52	74	4.43	+ 0.8	11	8,416	s.	37	se.	1	15	13	3	4.2	.....	....
Del Rio	944	8	57	28.99	29.96	+ .11	75.4	− 1.5	100	5	84	56	13	67	40	.....	.....	.....	8.91	+ 6.0	17	6,364	se.	39	sw.	12	6	15	10	5.9	.....	....
Roswell	3,566	75	85	26.39	29.95	+ .13	66.9	− 2.5	90	10	78	48	14	56	38	56	48	59	3.77	+ 2.6	7	6,960	se.	46	se.	26	7	13	11	5.8	.....	....
Southern Plateau.							65.6	− 0.4											42	0.77	+ 0.5								3.2		
El Paso	3,762	110	133	.....	29.86	+ .08	71.2	− 0.9	97	9	84	45	2	59	32	.....	.....	.....	1.23	+ 0.9	5	9,986	e.	60	ne.	29	17	9	5	.....	.....	....
Santa Fe	7,013	57	62	23.30	29.90	+ .09	56.2	− 0.5	78	9	68	32	2	45	32	44	33	49	2.28	+ 1.2	10	6,765	se.	44	sw.	27	7	22	2	4.8	0.2	....
Flagstaff	6,908	8	57	23.36	29.88	+ .10	50.2	− 0.5	80	21	68	20	1	33	44	.....	.....	.....	0.44	.....	3	.....	sw.	37	sw.	22	18	6	7	.....	.....	....
Phoenix	1,108	76	81	28.68	29.82	+ .04	75.6	+ 0.8	104	21	91	48	1	60	39	54	35	27	T.	0.0	0	4,337	e.	35	s.	31	15	9	7	4.1	.....	....
Yuma	141	9	58	29.68	29.82	+ .03	76.8	0.0	106	20	94	53	11	60	43	59	47	43	T.	0.0	0	4,033	sw.	26	sw.	1	30	1	0	0.6	.....	....
Independence	3,910	11	42	25.96	29.91	+ .07	63.4	− 1.1	90	29	78	35	1	48	37	50	39	49	0.34	+ 0.2	1	5,045	se.	32	se.	22	22	8	1	3.2	.....	....
Middle Plateau.							59.1	+ 2.9											46	0.69	− 0.5								4.4		
Reno	4,532	74	81	25.44	29.90	− .01	58.8	+ 5.2	88	30	74	37	26	44	44	45	35	50	0.11	− 0.7	2	5,288	w.	36	w.	9	16	9	6	3.9	.....	....
Tonopah	6,090	12	20	24.03	29.86	.....	58.8	.....	81	29	70	34	1	48	30	44	29	38	0.28	− 1.1	3	6,432	se.	31	se.	14	8	20	3	5.0	.....	....
Winnemucca	4,344	18	56	25.58	29.93	+ .02	59.4	+ 5.0	92	30	75	34	5	43	41	46	35	51	0.48	− 0.6	4	4,493	ne.	32	se.	21	15	8	8	4.2	.....	....
Modena	5,479	10	43	24.59	29.88	+ .06	56.6	+ 2.1	84	29	72	31	1	41	38	42	28	41	0.85	0.0	4	8,029	sw.	47	sw.	23	8	17	6	5.2	T.	....
Salt Lake City	4,360	147	189	25.58	29.90	+ .04	62.4	+ 4.1	86	30	74	37	1	51	32	49	38	45	0.80	− 1.1	7	6,116	nw.	45	sw.	19	20	10	1	3.4	.....	....
Durango	6,546	18	56	23.69	29.94	+ .12	54.6	− 0.4	81	21	71	32	3	39	43	42	34	57	1.62	+ 0.5	10	4,430	nw.	28	ne.	4	11	16	4	4.4	.....	....
Grand Junction	4,602	43	51	25.36	29.91	+ .08	62.8	+ 1.2	87	31	76	38	2	50	34	48	35	43	0.62	− 0.3	8	6,308	se.	42	sw.	22	12	14	5	4.4	.....	....
Northern Plateau.							59.4	+ 2.5											53	0.91	− 0.8								4.5		
Baker	3,471	48	53	26.74	30.01	+ .05	54.8	+ 4.1	85	30	69	27	5	41	41	45	36	57	0.87	− 0.9	5	4,687	s.	26	sw.	8	15	13	3	3.6	.....	....
Boise	2,739	78	86	27.12	29.96	+ .02	61.2	+ 3.6	93	31	75	35	5	48	39	49	37	49	0.51	− 0.8	5	4,133	nw.	34	sw.	21	14	9	8	4.5	.....	....
Lewiston	757	40	48	29.18	29.98	+ .02	62.4	+ 1.6	94	31	77	38	5	48	41	.....	.....	.....	1.15	− 0.5	9	2,580	ne.	33	n.	10	13	14	4	4.1	.....	....
Pocatello	4,477	46	54	25.45	29.93	+ .04	57.4	+ 1.9	88	31	71	28	5	44	44	46	35	53	1.32	− 0.9	11	5,185	se.	36	sw.	9	11	11	9	5.0	T.	....
Spokane	1,929	101	110	27.95	29.98	+ .02	58.5	+ 2.4	89	31	71	37	5	46	37	48	38	54	0.63	− 1.0	9	4,528	sw.	32	sw.	8	7	13	11	5.5	.....	....
Walla Walla	1,000	107	115	28.92	29.99	+ .03	62.2	+ 1.5	90	31	75	39	5	50	37	51	40	50	0.98	− 0.8	8	3,629	s.	26	w.	3	16	7	8	4.3	.....	....
North Pacific Coast Region.							55.7	+ 2.5											74	1.17	− 1.4								4.9		
North Head	211	11	56	29.84	30.07	+ .04	52.6	+ 1.4	80	21	56	46	28	49	24	50	48	87	1.71	− 0.7	11	13,527	nw.	48	nw.	14	10	12	9	5.2	.....	....
Port Crescent	259	8	53	29.80	30.08	+ .06	50.3	+ 1.2	82	22	61	31	16	40	37	.....	.....	.....	0.53	− 1.8	7	3,742	nw.	14	e.	21	11	14	6	4.8	.....	....
Seattle	125	215	250	29.93	30.06	+ .05	57.3	+ 2.3	78	22	66	43	28	49	26	52	47	73	0.74	− 1.6	6	7,004	n.	28	ne.	27	10	10	11	5.6	.....	....
Tacoma	213	113	120	29.83	30.05	+ .03	56.8	+ 2.3	77	22	66	40	28	48	26	51	46	70	1.00	− 1.5	9	5,446	n.	25	sw.	3	10	12	9	5.5	.....	....
Tatoosh Island	86	7	57	29.96	30.06	+ .05	52.0	+ 2.4	79	21	56	44	27	47	26	49	47	86	1.90	− 2.2	9	9,354	s.	40	ne.	21	13	6	12	5.2	.....	....
Portland, Oreg	153	68	106	29.86	30.02	− .01	61.1	+ 4.3	87	13	72	40	4	51	32	52	45	62	1.22	− 1.1	9	4,992	nw.	24	w.	3	15	8	8	4.3	.....	....
Roseburg	510	9	57	29.47	30.02	− .01	59.7	+ 3.7	92	21	74	34	4	45	42	51	44	66	1.06	− 1.0	8	2,264	n.	24	ne.	21	15	14	2	3.5	.....	....
Middle Pacific Coast Region.							58.3	+ 0.7											72	0.50	− 0.8								4.6		
Eureka	62	73	89	29.98	30.05	.00	53.0	+ 0.9	73	22	57	42	5	49	22	50	48	86	0.70	− 1.8	8	5,026	n.	30	n.	27	5	12	14	6.6	.....	....
Mount Tamalpais	2,375	11	18	27.53	29.99	− .01	55.1	+ 1.4	79	31	62	42	21	48	26	48	41	66	0.76	− 0.8	7	9,191	nw.	49	sw.	22	17	6	8	4.3	.....	....
Point Reyes Light	490	7	18	29.45	29.97	.....	52.3	+ 0.7	62	8	55	46	6	49	13	.....	.....	.....	0.38	.....	7	13,759	nw.	65	nw.	27	3	10	18	7.7	.....	....
Red Bluff	332	50	56	29.57	29.92	− .03	68.2	+ 1.7	101	30	81	50	7	56	37	56	48	56	0.47	− 0.8	3	3,376	se.	17	n.	28	19	9	3	3.1	.....	....
Sacramento	69	106	117	29.88	29.95	+ .01	62.8	− 0.1	90	29	74	48	5	52	34	56	50	69	0.50	− 0.5	2	6,419	s.	28	s.	14	26	2	3	2.3	.....	....
San Francisco	155	200	204	29.83	30.00	+ .01	56.2	+ 0.7	71	11	61	48	6	51	19	51	49	81	0.37	− 0.4	5	7,519	w.	31	w.	30	12	9	10	4.8	.....	....
San Jose	141	12	110	29.85	30.00	.....	60.4	− 0.3	85	29	71	42	28	50	38	.....	.....	.....	0.19	− 0.5	4	4,450	nw.	24	s.	22	17	11	3	3.6	.....	....
South Pacific Coast Region.							61.8	+ 0.2											72	0.14	− 0.4								5.2		
Fresno	327	89	98	29.58	29.94	+ .02	68.8	+ 0.4	99	31	83	49	10	55	37	55	45	51	T.	− 0.6	0	6,313	nw.	27	nw.	13	20	9	2	3.1	.....	....
Los Angeles	338	159	191	29.63	30.00	+ .05	60.3	− 0.2	73	11	67	48	2	53	23	55	52	80	0.43	0.0	2	3,854	s.	19	w.	25	7	11	13	6.3	.....	....
San Diego	87	62	70	29.90	29.99	+ .04	60.2	− 0.6	69	25	64	50	1	56	14	55	53	80	0.08	− 0.3	1	4,866	w.	22	w.	9	8	15	8	5.8	.....	....
San Luis Obispo	201	47	54	29.82	30.04	+ .04	58.0	+ 1.3	79	11	67	41	2	49	32	52	49	79	0.06	− 0.8	3	3,954	nw.	22	nw.	8	7	14	10	5.7	.....	....
West Indies.																															
San Juan	82	8	54	29.93	30.01	+ .02	77.8	.....	89	2	83	71	6	73	16	.....	.....	.....	13.50	+ 8.8	27	8,924	e.	36	ne.	5	7	18	6	5.4	.....	....
Panama.																															
Ancon	92	6	69	29.71	29.81	.....	82.0	.....	95	18	90	71	27	74	19	76	75	86	6.98	− 1.6	19	5,348	nw.	22	s	13	0	8	23	8.0	.....	....
Culebra	404	5	62	29.42	29.83	.....	81.4	.....	94	19	89	71	3	74	22	75	74	88	13.26	− 3.2	16	5,515	nw.	25	ne.	13	0	6	25	8.5	.....	....
Colon	10	5	71	29.83	29.84	.....	81.7	.....	88	21	86	72	7	78	12	78	76	86	17.76	+ 1.6	19	8,161	n.	28	ne.	9	1	15	15	7.1	.....	....

TABLE II.—*Accumulated amounts of precipitation for each 5 minutes, for the principal storms in which the rate of fall equaled or exceeded 0.25 inch in any 5 minutes, or 0.80 in 1 hour, during May, 1914, at all stations furnished with self-registering gages.*

Stations.	Date.	Total duration.		Total amount of precipitation.	Excessive rate.		Amount before excessive rate began.	Depths of precipitation (in inches) during periods of time indicated.													
		From—	To—		Began—	Ended—		5 min.	10 min.	15 min.	20 min.	25 min.	30 min.	35 min.	40 min.	45 min.	50 min.	60 min.	80 min.	100 min.	120 min.
Abilene, Tex.	26	7.08 p. m.	D. N. p. m.	1.94	10.52 p. m.	11.25 p. m.	0.39	0.22	0.57	0.72	0.87	1.10	1.37	1.50	.....	.....	.....	.....	.....	.....	.....
Albany, N. Y.	12	.....	.....	0.99	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	0.22	.....	.....	.....
Alpena, Mich.	29	3.20 p. m.	5.45 p. m.	1.18	3.20 p. m.	3.35 p. m.	.00	.41	.94	1.04	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Amarillo, Tex.	16–17	7.07 p. m.	5.15 a. m.	1.60	2.20 a. m.	3.09 a. m.	.13	.11	.25	.43	.60	.69	.79	.92	1.04	1.10	.....	.....	.....	.....	.....
Anniston, Ala.	7	.....	.....	0.50	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.45	.....	.....	.....
Asheville, N. C.	5	.....	.....	0.32	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.21	.....	.....	.....
Atlanta, Ga.	7	.....	.....	0.16	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.14	.....	.....	.....
Atlantic City, N. J.	8	.....	.....	0.44	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.21	.....	.....	.....
Augusta, Ga.	5	.....	.....	0.03	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.03	.....	.....	.....
Baker, Oreg.	21	.....	.....	0.50	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.19	.....	.....	.....
Baltimore, Md.	5	.....	.....	0.75	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.32	.....	.....	.....
Bentonville, Ark.	11	.....	.....	0.56	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.33	.....	.....	.....
Binghamton, N. Y.	4	.....	.....	0.46	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.46	.....	.....	.....
Birmingham, Ala.	7	.....	.....	0.50	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.45	.....	.....	.....
Bismarck, N. Dak.	4	.....	.....	1.33	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.52	.....	.....	.....
Block Island, R. I.	5	.....	.....	2.22	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.59	.....	.....	.....
Boise, Idaho	24–25	.....	.....	0.37	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.10	.....	.....	.....
Boston, Mass.	5	.....	.....	1.29	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.32	.....	.....	.....
Buffalo, N. Y.	4	.....	.....	0.61	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.50	.....	.....	.....
Burlington, Vt.	23	.....	.....	0.09	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.08	.....	.....	.....
Cairo, Ill.	4	7.00 p. m.	8.30 p. m.	0.81	7.20 p. m.	8.01 p. m.	.01	.07	.13	.25	.48	.55	.58	.62	.73	.78	.....	.....	.....	.....	.....
Canton, N. Y.	31	.....	.....	0.36	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.26	.....	.....	.....
Charles City, Iowa	24	.....	.....	2.45	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.63	.....	.....	.....
Charleston, S. C.	14	.....	.....	0.50	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.40	.....	.....	.....
Charlotte, N. C.	5	.....	.....	0.34	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.30	.....	.....	.....
Chattanooga, Tenn.	5	.....	.....	0.28	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.27	.....	.....	.....
Cheyenne, Wyo.	18	.....	.....	0.39	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.34	.....	.....	.....
Chicago, Ill.	27	.....	.....	0.70	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.59	.....	.....	.....
Cincinnati, Ohio	4	.....	.....	0.70	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.27	.....	.....	.....
Cleveland, Ohio	11–12	9.09 p. m.	7.30 a. m.	1.84	9.13 p. m.	9.38 p. m.	.01	.27	.61	.69	.76	.81	.....	.....	.....	.....	.....	.....	.....	.....	.....
Columbia, Mo.	11	.....	.....	0.97	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.61	.....	.....	.....
Columbia, S. C.	7	.....	.....	0.27	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.27	.....	.....	.....
Columbus, Ohio	4	.....	.....	0.47	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.25	.....	.....	.....
Concord, N. H.	5–6	.....	.....	0.69	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	(*)	.....	.....	.....
Concordia, Kans.	21	2.20 a. m.	4.45 a. m.	0.75	2.35 a. m.	2.55 a. m.	.02	.12	.37	.46	.55	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Corpus Christi, Tex.	18	8.33 a. m.	12.50 p. m.	1.20	10.00 a. m.	10.35 a. m.	.18	.12	.28	.45	.55	.65	.72	.78	.....	.....	.....	.....	.....	.....	.....
Dallas, Tex.	4	4.50 a. m.	8.20 a. m.	2.12	5.03 a. m.	6.36 a. m.	.02	.19	.33	.35	.35	.38	.42	.45	.53	.63	.80	1.06	1.69	1.85	.....
Do.	27	6.30 a. m.	9.35 a. m.	1.36	8.27 a. m.	9.07 a. m.	.01	.22	.33	.37	.59	.67	.87	1.07	1.21	.....	.....	.....	.....	.....	.....
Do.	29	10.30 a. m.	7.15 p. m.	1.10	11.25 a. m.	11.54 a. m.	.01	.11	.29	.44	.52	.55	.63	.....	.....	.....	.....	.....	.....	.....	.....
Davenport, Iowa	11	.....	.....	0.68	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.28	.....	.....	.....
Dayton, Ohio	7	.....	.....	0.22	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.20	.....	.....	.....
Del Rio, Tex.	18	12.40 a. m.	3.50 a. m.	1.98	2.15 a. m.	3.15 a. m.	.04	.09	.16	.26	.45	.76	.99	1.17	1.38	1.58	1.75	1.85	.....	.....	.....
	20	5.50 a. m.	11.50 a. m.	2.10	10.07 a. m.	11.45 a. m.	.39	.10	.21	.34	.49	.62	.75	.82	.85	.87	.88	.98	1.44	1.68	.....
	24–25	11.50 p. m.	5.15 a. m.	1.78	12.28 a. m.	1.26 a. m.	.06	.14	.24	.30	.49	.87	1.15	1.31	1.39	1.44	1.46	1.63	.....	.....	.....
Denver, Colo.	21	4.03 p. m.	4.55 p. m.	0.86	4.14 p. m.	4.31 p. m.	.01	.13	.47	.83	.85	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
		5.32 p. m.	7.50 p. m.	1.08	5.38 p. m.	6.13 p. m.	.01	.06	.17	.27	.51	.66	.84	.90	.....	.....	.....	.....	.....	.....	.....
Des Moines, Iowa	10	9.17 p. m.	D. N. p. m.	1.27	9.39 p. m.	10.04 p. m.	.01	.14	.44	.83	1.04	1.22	.....	.....	.....	.....	.....	.....	.....	.....	.....
	11	1.30 a. m.	2.05 a. m.	1.27	1.36 a. m.	1.57 a. m.	.01	.11	.45	.97	1.21	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
	23	6.25 p. m.	8.05 p. m.	1.46	6.42 p. m.	7.11 p. m.	.01	.46	.80	.94	1.05	1.17	1.32	.....	.....	.....	.....	.....	.....	.....	.....
Detroit, Mich.	11	.....	.....	1.91	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.37	.....	.....	.....
Devils Lake, N. Dak.	2	.....	.....	0.34	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.12	.....	.....	.....
Dodge City, Kans.	1	.....	.....	2.15	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.54	.....	.....	.....
Dubuque, Iowa	3	4.20 p. m.	8.37 p. m.	0.74	6.48 p. m.	7.00 p. m.	.11	.19	.49	.56	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
	25	9.40 p. m.	11.10 p. m.	0.76	9.46 p. m.	10.01 p. m.	.01	.28	.45	.68	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Duluth, Minn.	28	8.25 a. m.	D. N. p. m.	2.42	7.00 p. m.	8.03 p. m.	1.20	.05	.14	.21	.30	.32	.34	.34	.52	.83	.97	1.05	1.12	.....	.....
Durango, Colo.	15	.....	.....	1.00	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	(*)	.....	.....	.....
Eastport, Me.	23	.....	.....	0.14	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.14	.....	.....	.....
Elkins, W. Va.	5	.....	.....	1.02	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.26	.....	.....	.....
El Paso, Tex.	(‡)	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Erie, Pa.	5	.....	.....	2.74	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.70	.....	.....	.....
Escanaba, Mich.	29	.....	.....	0.14	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.11	.....	.....	.....
Eureka, Cal.	24	.....	.....	0.55	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.19	.....	.....	.....
Evansville, Ind.	5–6	.....	.....	0.75	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.50	.....	.....	.....
Flagstaff, Ariz.	30	.....	.....	0.31	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	(*)	.....	.....	.....
Fort Smith, Ark.	4	D. N. a. m.	5.18 a. m.	1.10	2.56 a. m.	4.02 a. m.	.04	.18	.29	.39	.53	.55	.57	.61	.65	.68	.71	.89	1.00	.....	.....
	19	D. N. a. m.	1.10 p. m.	1.34	6.15 a. m.	6.56 a. m.	.36	.14	.24	.33	.39	.47	.56	.59	.65	.68	.....	.....	.....	.....	.....
Fort Wayne, Ind.	11	4.50 a. m.	7.45 a. m.	0.79	5.24 a. m.	5.44 a. m.	.02	.31	.48	.54	.59	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Fort Worth, Tex.	20	2.11 p. m.	11.50 p. m.	1.40	9.19 p. m.	9.40 p. m.	.70	.13	.27	.44	.55	.58	.....	.....	.....	.....	.....	.....	.....	.....	.....
	29–30	12.06 p. m.	1.10 a. m.	2.63	12.28 p. m.	1.42 p. m.	.01	.18	.26	.30	.31	.31	.34	.61	.83	1.11	1.19	1.25	1.52	.....	.....
Fresno, Cal.	25	.....	.....	T.	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	T.	.....	.....	.....
Galveston, Tex.	19	6.55 a. m.	10.45 a. m.	1.48	9.19 a. m.	9.50 a. m.	.31	.14	.46	.73	.89	1.00	1.09	1.13	.....	.....	.....	.....	.....	.....	.....
	29	10.25 a. m.	6.00 p. m.	2.81	11.07 a. m.	12.41 p. m.	.01	.14	.18	.30	.40	.46	.58	.68	.78	.83	.89	1.11	1.32	1.48	.....
Grand Haven, Mich.	24	.....	.....	1.21	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.45	.....	.....	.....
Grand Junction, Colo.	22	.....	.....	0.25	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.21	.....	.....	.....
Grand Rapids, Mich.	11	.....	.....	1.16	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.30	.....	.....	.....
Green Bay, Wis.	21	.....	.....	2.45	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.48	.....	.....	.....
Hannibal, Mo.	28	.....	.....	0.41	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.34	.....	.....	.....
Harrisburg, Pa.	4	6.55 p. m.	D. N. p. m.	0.61	7.08 p. m.	7.33 p. m.	.01	.06	.12	.21	.43	.52	.....	.....	.....	.....	.....	.....	.....	.....	.....
Hartford, Conn.	12	.....	.....	0.72	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.46	.....	.....	.....
Hatteras, N. C.	5	.....	.....	0.46	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.32	.....	.....	.....
Havre, Mont.	8–9	.....	.....	0.49	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.41	.....	.....	.....
Helena, Mont.	10	.....	.....	1.45	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.18	.....	.....	.....
Houghton, Mich.	28	.....	.....	0.47	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.39	.....	.....	.....
Houston, Tex.	12–13	12.20 p. m.	D. N. a. m.	5.15	1.09 p. m.	2.38 p. m.	.27	.10	.24	.38	.62	1.00	1.18	1.42	1.75	1.99	2.16	2.40	2.84	3.14	.....
Do.	27	8.58 a. m.	2.20 p. m.	1.38	9.47 a. m.	10.13 a. m.	.07	.19	.28	.32	.47	.62	.67	.....	.....	.....	.....	.....	.....	.....	.....
Do.	27–28	9.05 p. m.	D. N. a. m.	2.90	9.59 p. m.	10.54 p. m.	.32	.07	.12	.24	.78	1.24	1.56	1.85	2.01	2.02	2.09	2.20	.....	.....	.....
					10.21 p. m.	11.11 p. m.	.19	.09	.16	.18	.20	.32	.40	.51	.58	.68	.94	.....	.....	.....	.....
Do.	28–29	9.10 p. m.	D. N. a. m.	3.18	11.11 p. m.	12.01 a. m.	.....	1.06	1.15	1.26	1.39	1.50	1.59	1.71	1.81	1.84	1.95	.....	.....	.....	.....
					12.01 a. m.	12.31 a. m.	.....	2.02	2.17	2.41	2.58	2.73	2.82	2.85	.....	.....	.....	.....	.....	.....	.....
Huron, S. Dak.	20–21	5.47 p. m.	D. N. a. m.	2.70	6.04 p. m.	7.07 p. m.	.08	.09	.29	.45	.59	.69	.82	1.10	1.40	1.63	1.77	1.97	2.10	.....	.....
Independence, Cal.	Apr. 30	.....	.....	0.38	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	(*)	.....	.....	.....
	May 1	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Indianapolis, Ind.	4	.....	.....	0.98	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.73	.....	.....	.....
Iola, Kans.	11	4.15 p. m.	8.50 p. m.	1.09	4.46 p. m.	5.15 p. m.	.04	.09	.20	.34	.48	.61	.73	.....	.....	.....	.....	.....	.....	.....	.....
	21	2.56 p. m.	7.48 p. m.	1.83	3.36 p. m.	4.16 p. m.	.03	.14	.38	.67	.88	1.16	1.29	1.34	1.40	.....	.....	.....	.....	.....	.....
	29	12.40 p. m.	3.06 p. m.	0.69	1.20 p. m.	1.50 p. m.	.01	.09	.19	.25	.34	.45	.55	.....	.....	.....	.....	.....	.....	.....	.....
Jacksonville, Fla.	18	12.50 p. m.	4.40 p. m.	0.75	1.49 p. m.	2.06 p. m.	.13	.13	.35	.50	.54	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Kalispell, Mont.	23	.....	.....	0.23	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.14	.....	.....	.....

TABLE II.—*Accumulated amounts of precipitation for each 5 minutes, for the principal storms in which the rate of fall equaled or exceeded 0.25 inch in any 5 minutes, or 0.80 in 1 hour, during May, 1914, at all stations furnished with self-registering gages*—Continued.

Stations.	Date.	Total duration.		Total amount of precipitation.	Excessive rate.		Amount before excessive rate began.	Depths of precipitation (in inches) during periods of time indicated.												
		From—	To—		Began—	Ended—		5 min.	10 min.	15 min.	20 min.	25 min.	30 min.	35 min.	40 min.	45 min.	50 min.	60 min.	80 min.	100 min.	120 min.
Kansas City, Mo.	2			0.19														.16			
Keokuk, Iowa	9			0.49														.49			
Key West, Fla.	20			1.05														.47			
Knoxville, Tenn.	5			0.72														.53			
La Crosse, Wis.	21			1.05														.48			
Lander, Wyo.	11			0.19														(*)			
Lansing, Mich.	27	6.08 a. m.	8.45 a. m.	0.65	6.16 a. m.	6.29 a. m.	.01	.14	.45	.52											
Lewiston, Idaho	22			0.45														.45			
Lexington, Ky.	4			0.81														.39			
Lincoln, Nebr.	26–27	11.50 p. m.	3.30 a. m.	2.90	11.57 p. m.	12.46 a. m.	.02	.28	.72	.96	1.31	1.53	1.89	2.07	2.39	2.47	2.72				
Little Rock, Ark.	4			1.94														.56			
Los Angeles, Cal.	1			0.42														.22			
Louisville, Ky.	4			0.37														.14			
Ludington, Mich.	21			0.97														.53			
Lynchburg, Va.	5			0.40														.14			
Macon, Ga.	5			0.26														.26			
Madison, Wis.	3	6.10 p. m.	9.40 p. m.	1.26	6.59 p. m.	7.38 p. m.	.12	.12	.26	.34	.41	.49	.67	.75	.81						
	27–28	8.35 p. m.	D. N. a. m.	1.10	8.37 p. m.	9.17 p. m.	.01	.08	.24	.33	.46	.64	.77	.84	.90						
Marquette, Mich.	25			0.33														.29			
Memphis, Tenn.	4	10.00 a. m.	8.45 p. m.	4.28	11.59 a. m.	12.26 p. m.	.17	.11	.39	.57	.59	.69	.73								
					1.17 p. m.	3.10 p. m.	.98	.08	.15	.35	.48	.59	.74	.83	.86	.92	.98	1.20	1.40	1.78	2.08
Meridian, Miss.	17			0.42														.39			
Miami, Fla.	14			0.64														.22			
Milwaukee, Wis.	27			0.87														.71			
Minneapolis, Minn.	3			0.60														.27			
Mobile, Ala.	27			0.17														.16			
Modena, Utah	31			0.48														.45			
Montgomery, Ala.	7			0.45														.37			
Moorhead, Minn.	28			0.34														.20			
Mount Tamalpais, Cal.	22			0.19														.05			
Mount Weather, Va.	5			0.62														.20			
Nantucket, Mass.	8			0.91														.45			
Nashville, Tenn.	4	6.00 a. m.	8.25 a. m.	0.56	7.49 a. m.	8.14 a. m.	.05	.10	.16	.24	.40	.51									
	4–5	3.25 p. m.	6.40 a. m.	1.94	9.59 a. m.	10.33 p. m.	.53	.43	.64	.77	.91	1.04	1.18	1.25							
New Haven, Conn.	12			0.68														.29			
New Orleans, La.	27			0.14														.08			
New York, N. Y.	11			0.73														.52			
Norfolk, Va.	9	11.30 a. m.	3.10 p. m.	0.88	1.22 p. m.	1.52 p. m.	.17	.10	.23	.46	.56	.59	.66								
Northfield, Vt.	30			0.19														.11			
North Head, Wash.	9			0.41														.17			
North Platte, Nebr.	19			0.68														.63			
Oklahoma, Okla.	2			0.96														.60			
Omaha, Nebr.	28–29	11.20 p. m.	D. N. a. m.	0.95	11.46 p. m.	12.11 a. m.	.04	.13	.23	.34	.58	.72									
Oswego, N. Y.	5			0.66														.23			
Palestine, Tex.	3	11.35 a. m.	2.15 p. m.	0.91	1.22 p. m.	1.51 p. m.	.11	.15	.37	.48	.61	.72	.77								
	3	2.25 p. m.	9.10 p. m.	1.29	2.31 p. m.	2.47 p. m.	.01	.09	.36	.61	.63										
	7	12.25 p. m.	2.35 p. m.	0.76	12.50 p. m.	1.07 p. m.	.02	.28	.41	.57	.60										
Parkersburg, W. Va.	5			0.93														.20			
Pensacola, Fla.	5			0.09														.08			
Peoria, Ill.	11–12			1.32														.49			
Philadelphia, Pa.	5			0.63														.24			
Phoenix, Ariz.	22			T.														T.			
Pierre, S. Dak.	22			1.45														.97			
Pittsburgh, Pa.	12			0.69														.52			
Pocatello, Idaho	15			0.34														.17			
Point Reyes Light, Cal.	7			0.17														.07			
Port Huron, Mich.	4			0.23														.19			
Portland, Me.	8–9			1.11														.25			
Portland, Oreg.	13			0.28														.27			
Providence, R. I.	5			1.15														.18			
Pueblo, Colo.	May 31–June 1	6.20 p. m.	2.30 a. m.	1.72	10.50 p. m.	11.15 p. m.	.33	.18	.36	.55	.88	.97									
Raliegh, N. C.	5			0.50														.21			
Rapid City, S. Dak.	17			0.39														.39			
Reading, Pa.	5			0.57														.15			
Red Bluff, Cal.	9			0.31														.23			
Reno, Nev.	22			0.06														.05			
Richmond, Va.	30			0.93														.83			
Rochester, N. Y.	12			0.68														.22			
Roseburg, Oreg.	7			0.34														.29			
Roswell, N. Mex.	23	9.10 p. m.	9.40 p. m.	0.65	9.21 p. m.	9.35 p. m.	.01	.20	.40†	.60†											
	26	4.00 p. m.	6.05 p. m.	1.31	4.10 p. m.	4.40 p. m.	.01	.18	.47	.56	.66	.89	1.23								
Sacramento, Cal.	23			0.28														.14			
Saginaw, Mich.	27			0.66														.55			
St. Joseph, Mo.	27			0.27														.13			
St. Louis, Mo.	5			0.42														.27			
St. Paul, Minn.	11			0.45														.17			
Salt Lake City, Utah	19			0.35														.23			
San Antonio, Tex.	12	5.10 p. m.	9.15 p. m.	1.92	7.11 p. m.	7.59 p. m.	.30	.13	.42	.68	.88	1.08	1.22	1.33	1.40	1.51	1.58				
	20–21	12.42 p. m.	7.30 a. m.	1.83	4.36 a. m.	5.41 a. m.	.69	.16	.38	.47	.51	.53	.56	.59	.67	.76	.87	.99	1.08		
San Diego, Cal.	1			0.08														.05			
Sand Key, Fla.	24			1.25														.63			
Sandusky, Ohio	11			1.28														.56			
San Francisco, Cal.	22			0.24														.13			
San Jose, Cal.	25			0.05														.05			
San Luis Obispo, Cal.	4			0.02														.01			
Santa Fe, N. Mex.	May 31–June 1			0.77														(*)			
Sault Ste. Marie, Mich.	21			0.37														.19			
Savannah, Ga.	7			0.40														.36			
Scranton, Pa.	26			0.43														.42			
Seattle, Wash.	27			0.36														.20			
Sheridan, Wyo.	9			0.37														.37			
Shreveport, La.	4	10.50 a. m.	2.50 p. m.	1.64	1.04 p. m.	2.00 p. m.	.53	.15	.16	.18	.18	.20	.47	.51	.52	.65	.77	.87			
Sioux City, Iowa	28			0.99														.58			
Spokane, Wash.	27			0.21														.15			
Springfield, Ill.	5			0.46														.28			

TABLE II.—*Accumulated amounts of precipitation for each 5 minutes, for the principal storms in which the rate of fall equaled or exceeded 0.25 inch in any 5 minutes, or 0.80 in 1 hour, during May, 1914, at all stations furnished with self-registering gages*—Continued.

Stations.	Date.	Total duration.		Total amount of precipitation.	Excessive rate.		Amount before excessive rate began.	Depths of precipitation (in inches) during periods of time indicated.													
		From—	To—		Began—	Ended—		5 min.	10 min.	15 min.	20 min.	25 min.	30 min.	35 min.	40 min.	45 min.	50 min.	60 min.	80 min.	100 min.	120 min.
Springfield, Mo	4			1.54														1.10			
Syracuse, N. Y	4			0.42														.36			
Tacoma, Wash	13			0.21														.13			
Tampa, Fla	26	12.29 p. m.	3.05 p. m.	0.81	12.49 p. m.	1.09 p. m.	.12	.20	.47	.56	.63										
Tatoosh Island, Wash	24			0.71														.40			
Taylor, Tex	2	3.08 p. m.	6.38 p. m.	1.03	4.04 p. m.	4.18 p. m.	.30	.23	.51	.63											
	26	3.02 p. m.	6.39 p. m.	1.66	4.06 p. m.	4.43 p. m.	.17	.10	.21	.31	.46	.79	1.01	1.12	1.17						
Terre Haute, Ind	5			0.40														.23			
Thomasville, Ga	7	2.05 p. m.	5.25 p. m.	0.86	2.32 p. m.	2.52 p. m.	T.	.13	.37	.49	.62										
Toledo, Ohio	11	4.25 p. m.	9.00 p. m.	1.50	6.31 p. m.	7.31 p. m.	.02	.08	.15	.26	.44	.62	.73	.75	.79	1.03	1.21	1.34			
Tonopah, Nev	23			0.24														.17			
Topeka, Kans	2			0.50														.28			
Valentine, Nebr	24			0.33														.27			
Vicksburg, Miss	25			0.24														.24			
Walla Walla, Wash	27			0.34														.16			
Washington, D. C	27			0.74														.45			
Wichita, Kans	2	1.45 a. m.	11.15 a. m.	2.46	7.19 a. m.	8.25 a. m.	.96	.22	.36	.44	.48	.57	.59	.60	.64	.67	.70	.94	1.13		
Williston, N. Dak	18			0.23														.20			
Wilmington, N. C	14			0.07														.05			
Winnemucca, Nev	20			0.24														.19			
Wytheville, Va	5			0.96														.29			
Yankton, S. Dak	19-20	9.20 p. m.	6.25 a. m.	1.40	9.23 p. m.	9.48 p. m.	.01	.12	.30	.43	.53	.62									
Yellowstone Park, Wyo	18-19			0.53														(*)			

* Self-register does not work in freezing weather. † Record partly estimated. ‡ No precipitation occurred during month.

TABLE III.—*Data furnished by the Canadian Meteorological Service, May, 1914.*

Stations.	Pressure.			Temperature.						Precipitation.		
	Station reduced to mean of 24 hours.	Sea level reduced to mean of 24 hours.	Departure from normal.	Mean Max. + mean min. ÷2.	Departure from normal.	Mean maximum.	Mean minimum.	Highest.	Lowest.	Total.	Departure from normal.	Total snowfall.
	Inches.	*Inches.*	*Inches.*	*° F.*	*° F.*	*° F.*	*° F.*	*° F.*	*° F.*	*Inches.*	*Inches.*	*Inches.*
St. Johns, N. F	29.84	29.98	0.00	44.0	+1.1	50.8	37.3	75	28	3.43	−0.23	
Sydney, C. B. I	29.97	30.01	+ .04	46.7	+1.5	56.5	36.9	75	24	2.98	−0.79	4.0
Halifax, N. S	29.91	30.02	+ .04	49.4	+1.0	60.6	38.3	88	26	4.95	+0.69	1.4
Yarmouth, N. S	29.96	30.03	+ .05	48.0	+0.4	55.5	40.4	74	30	2.98	−0.82	0.4
Charlottetown, P. E. I	29.95	29.99	+ .03	48.2	+1.3	57.0	39.5	73	27	1.79	−1.12	7.0
Chatham, N. B	29.96	29.98	+ .03	51.8	+3.3	63.8	39.7	91	25	2.26	−0.95	0.3
Father Point, Que	29.92	29.94	+ .01	46.2	+2.2	54.8	37.7	74	25	3.43	+0.85	0.5
Quebec, Que	29.66	29.98	+ .04	55.0	+5.1	66.8	43.1	84	26	1.95	−1.13	
Montreal, Que	29.79	29.99	+ .05	58.8	+4.1	68.6	48.9	87	32	1.42	−1.53	
Stonecliffe, Ont	29.42	30.02	+ .09	55.4	+3.1	71.5	39.4	90	25	1.13	−1.38	
Ottawa, Ont	29.76	29.98	+ .04	58.4	+3.5	70.7	46.1	88	33	0.41	−2.18	
Kingston, Ont	29.76	30.07	+ .11	55.0	+2.1	63.3	46.8	77	30	2.28	−0.40	
Toronto, Ont	29.67	30.04	+ .06	58.6	+5.4	69.7	47.4	87	35	1.49	−1.55	
White River, Ont	28.71	30.03	+ .08	48.7	+3.0	65.4	32.0	82	10	0.84	−1.11	
Port Stanley, Ont	29.46	30.10	+ .13	53.7	+0.6	63.3	44.1	75	20	4.29	+1.11	
Southampton, Ont	29.39			53.4	+2.7	64.7	42.1	88	28	1.31	−1.13	
Parry Sound, Ont	29.38	30.08	+ .13	54.5	+3.4	67.0	42.0	81	27	1.51	−1.42	
Port Arthur, Ont	29.32	30.03	+ .07	52.3	+6.4	65.6	39.0	88	28	1.35	−0.80	
Winnipeg, Man	29.16	29.99	+ .03	55.2	+3.6	68.0	42.4	82	22	1.65	−0.63	
Minnedosa, Man	28.18	29.99	+ .03	52.6	+4.2	65.8	39.3	80	23	3.15	+1.70	
Qu'Appelle, Sask	27.71	29.95	+ .01	51.5	+1.7	64.5	38.5	82	20	2.59	+0.94	12.8
Medicine Hat, Alberta	27.67	29.93	+ .04	57.4	+3.3	72.3	42.5	90	26	0.55	−0.76	T.
Swift Current, Sask	27.38	29.95	+0.3	52.8	+2.1	68.5	37.1	86	16	0.17	−1.59	1.0
Calgary, Alberta	26.42	29.94	+ .06	50.8	+1.8	65.3	36.3	82	22	0.52	−1.25	
Banff, Alberta	25.40	29.98	+ .10	45.6	−1.4	58.3	32.9	77	23	1.46	−0.58	0.5
Edmonton, Alberta	27.75	30.04	+ .16	51.1	+0.3	63.2	38.9	78	29	1.81	+0.26	T.
Prince Albert, Sask	28.38	29.93	− .02	52.0	+4.4	65.6	38.5	81	24	2.54	+1.38	8.0
Battleford, Sask	28.22	29.95	+ .03	54.4	+3.4	66.5	42.2	85	27	2.86	+1.24	
Kamloops, B. C	28.76	30.03	+ .14	58.0	−1.1	71.0	44.9	86	35	1.31	+0.07	
Victoria, B. C	29.80	29.89	− .11	55.9	+3.4	64.2	47.6	81	42	0.18	−1.30	
Barkerville, B. C	25.68	29.99	+ .15	43.1	−2.4	54.8	31.3	70	23	3.22	+0.70	
Hamilton, Bermuda	30.02	30.18	+ .12	66.8	−2.6	72.3	61.4	76	54	5.16	+0.50	

Chart I. Hydrographs of Several Principal Rivers, May, 1914.

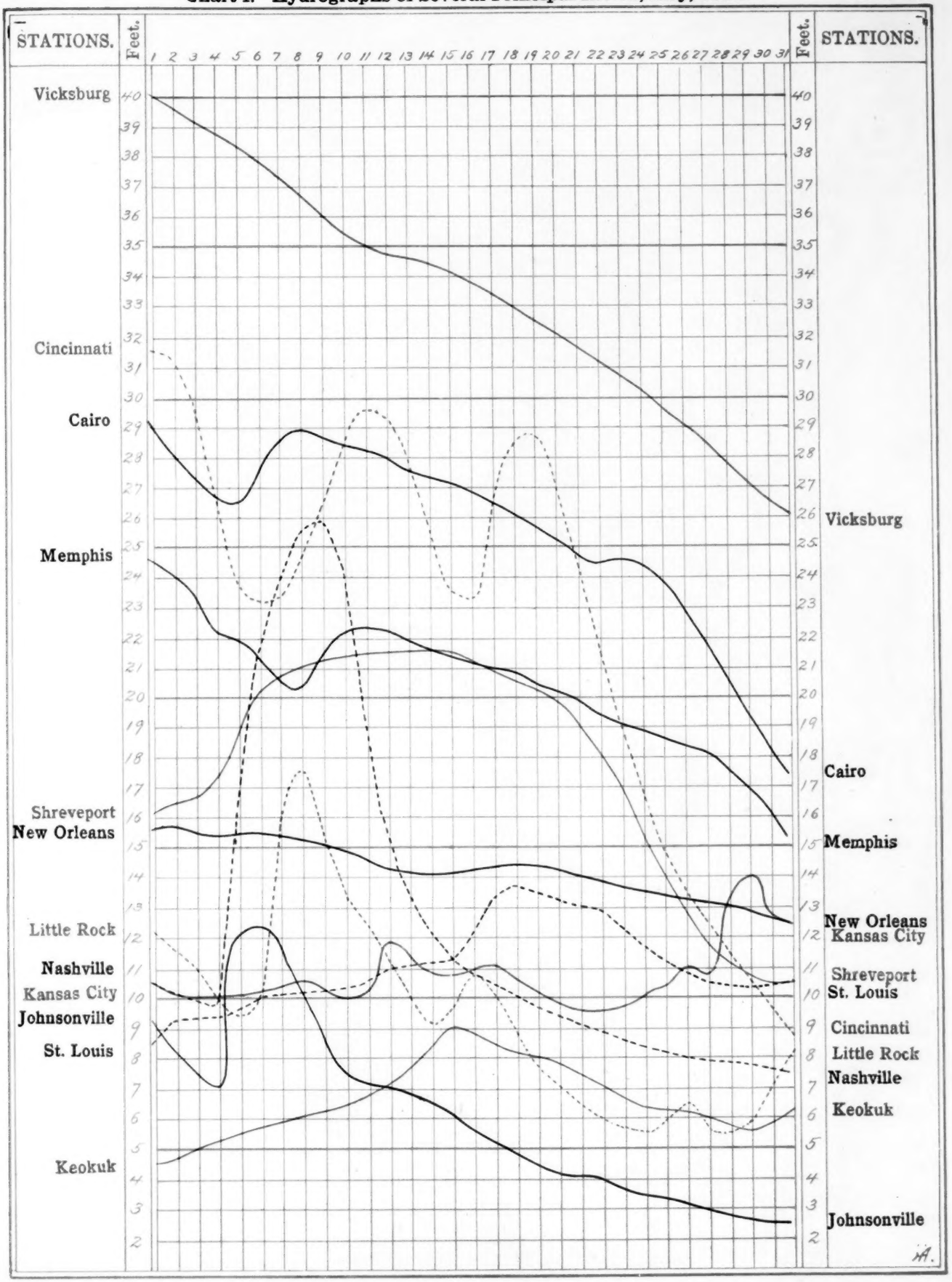


Chart II. Tracks of Centers of High Areas, May, 1914.

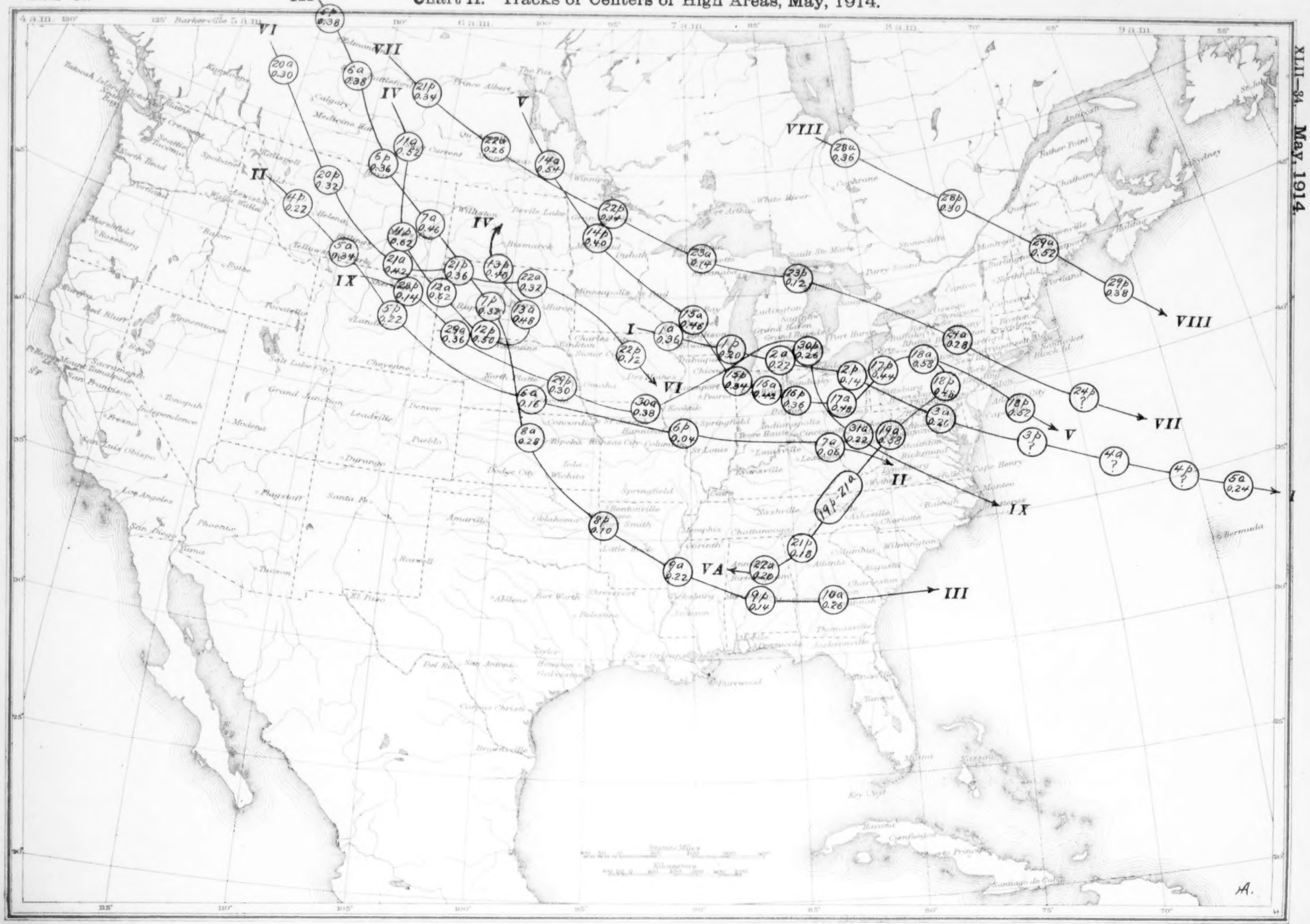
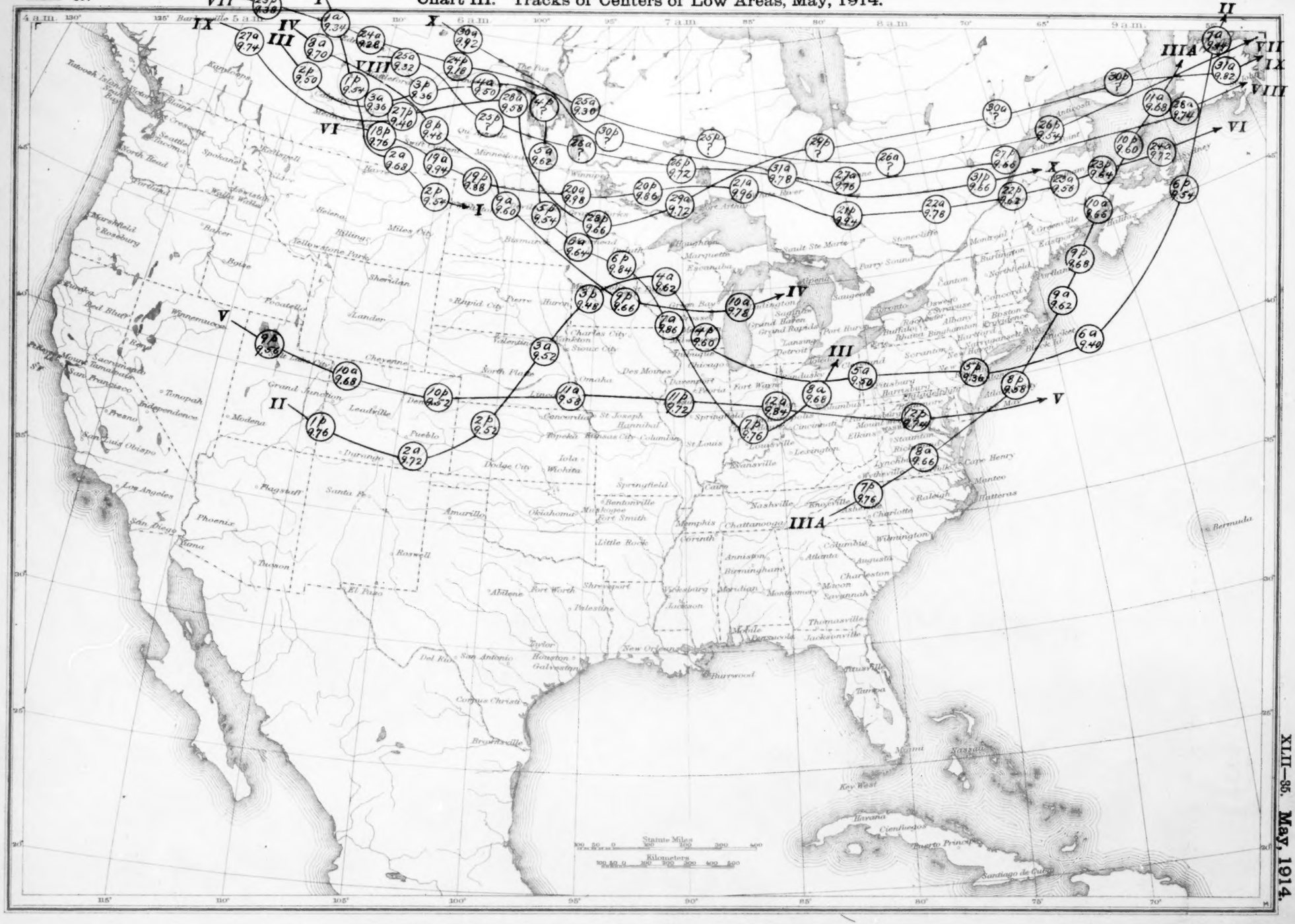


Chart III. Tracks of Centers of Low Areas, May, 1914.



XLII—36. Chart IV. Departure of the Mean Temperature from the Normal, May, 1914.

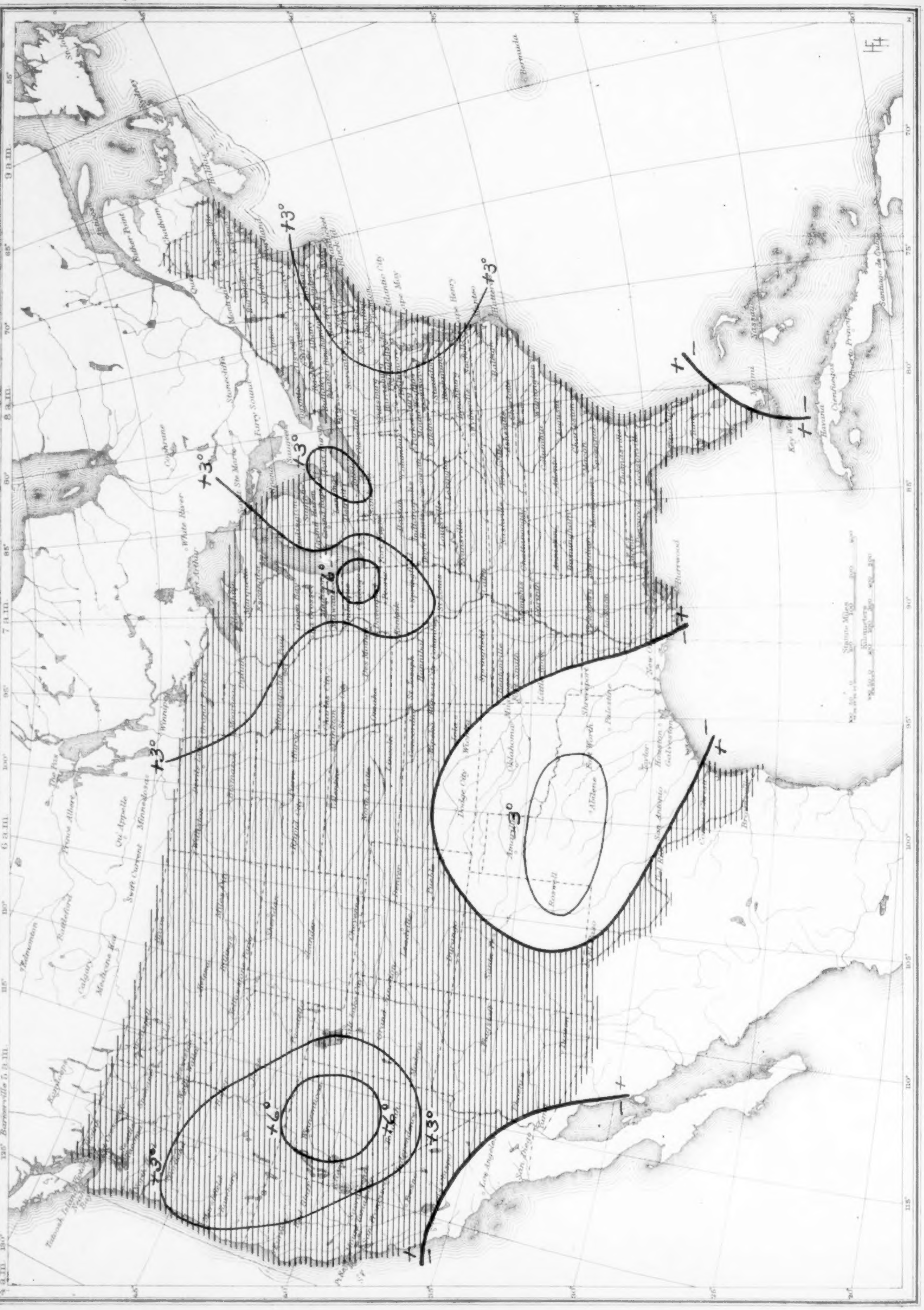


Chart V. Total Precipitation, inches, May, 1914.

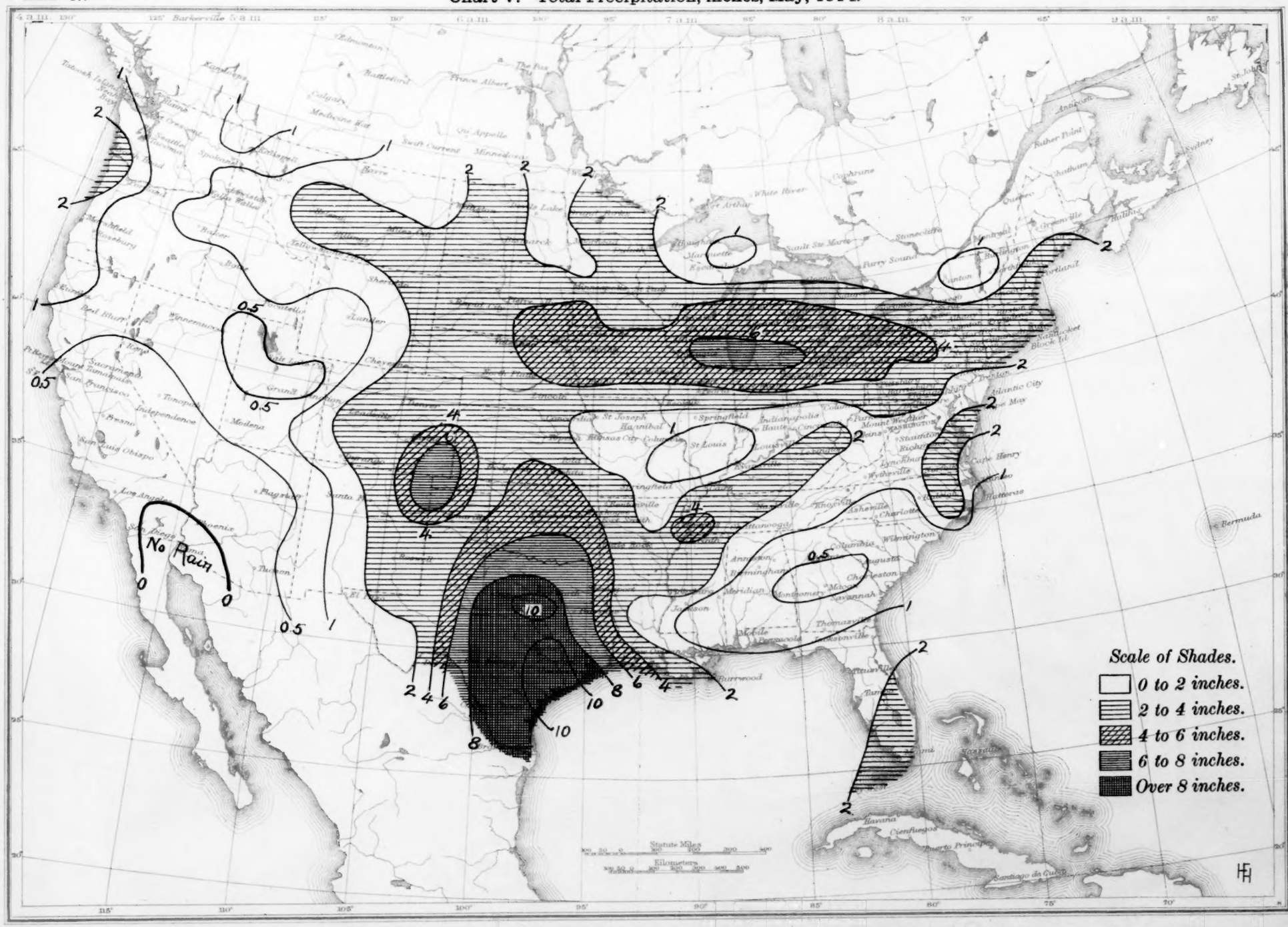


Chart VI. Percentage of Clear Sky between Sunrise and Sunset, May, 1914.

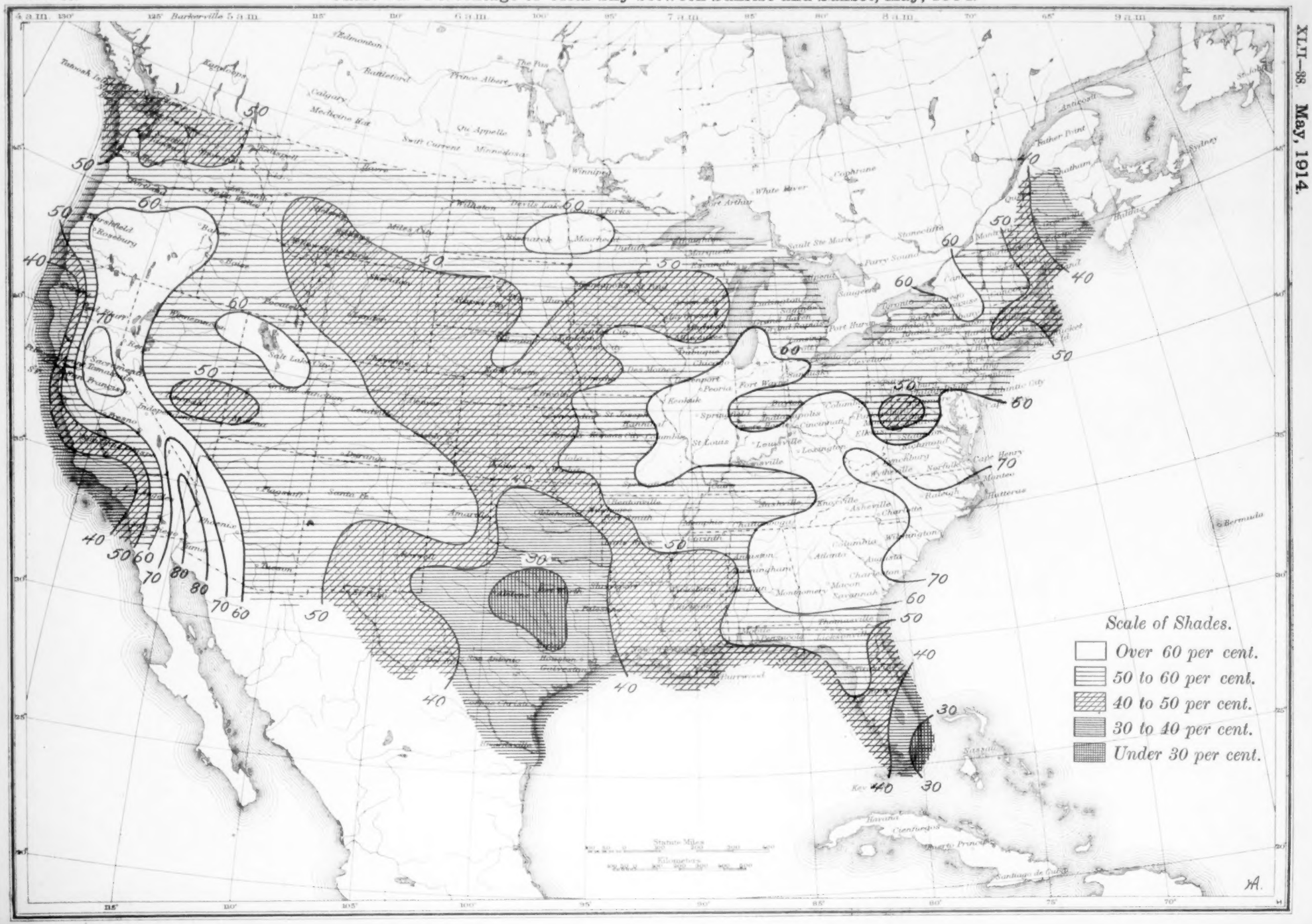


Chart VII. Isobars and Isotherms at Sea Level: Prevailing Winds, May, 1914.

Chart VII. Isobars and Isotherms at Sea Level; Prevailing Winds, May, 1914.

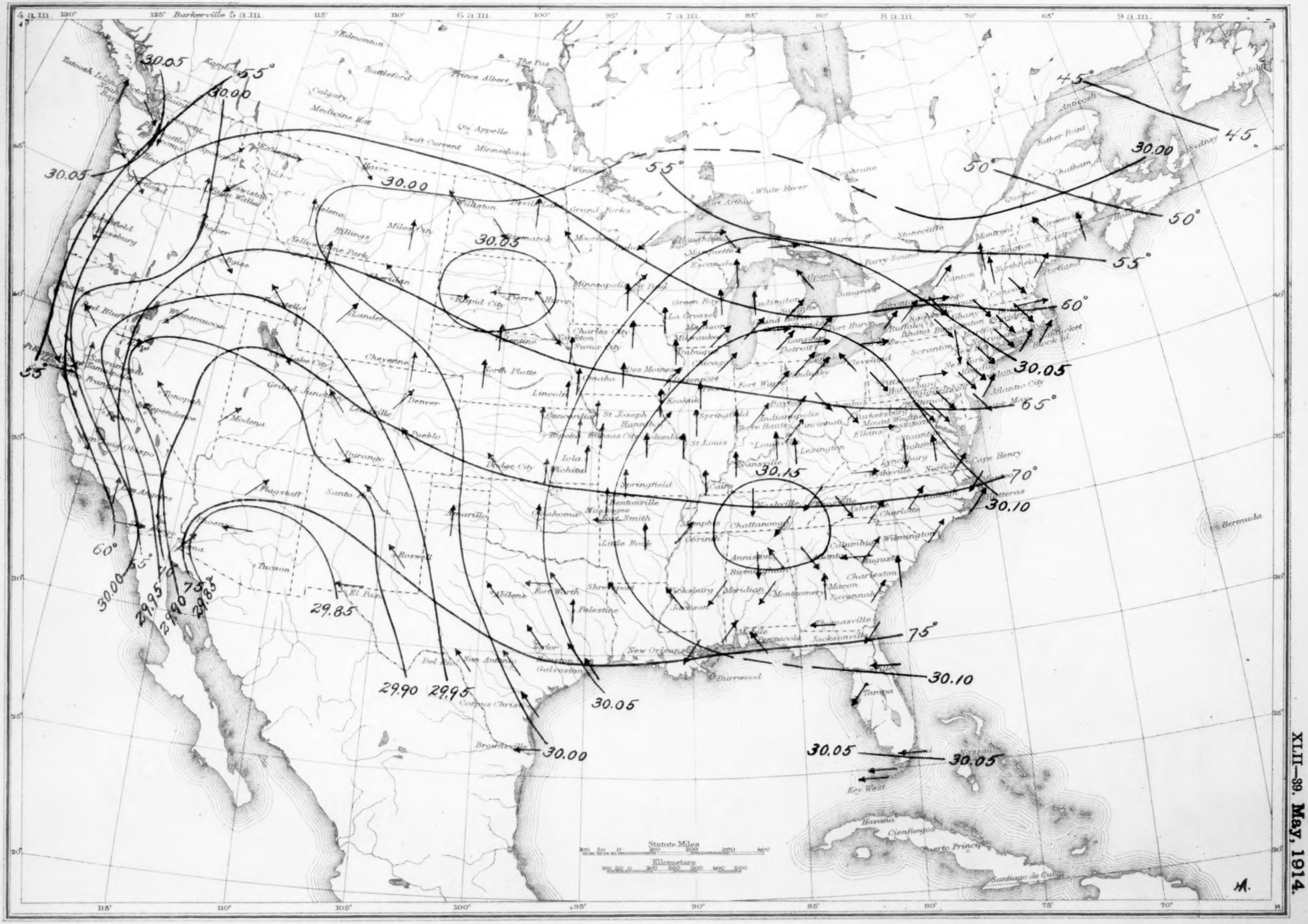
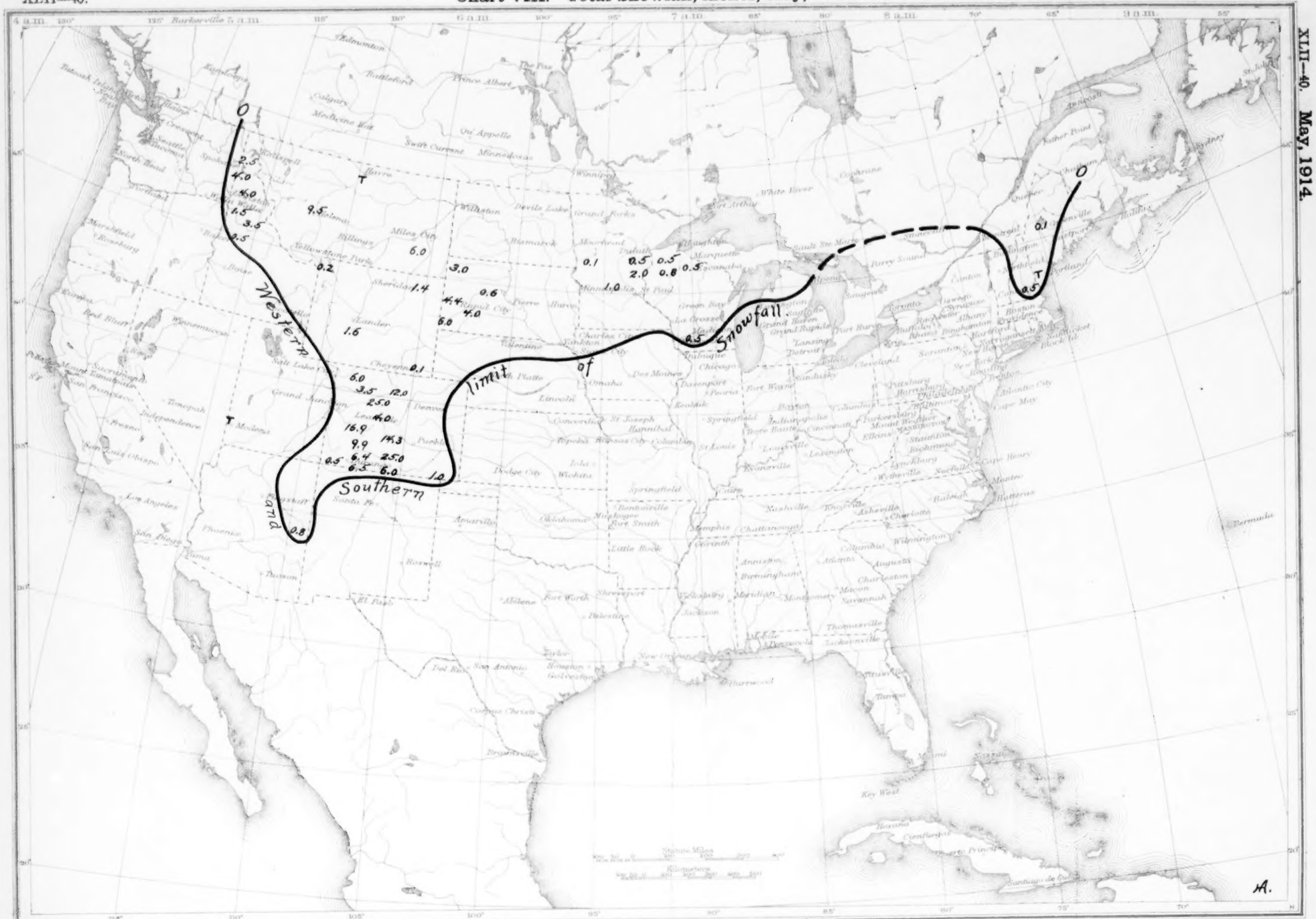


Chart VIII. Total Snowfall, inches, May, 1914.



XLII—40. May, 1914.

55828—14——1